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A methodology to assess and manage material and machine tool risks for a manufacturer

Ashutosh Anil Hengle
University of Tennessee

To the Graduate Council:

I am submitting herewith a thesis written by Ashutosh Anil Hengle entitled "A methodology to assess and manage material and machine tool risks for a manufacturer." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

Rapinder Sawhney, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Dr. Rapinder Sawhney
Major Professor

We have read this thesis and recommend its acceptance:

Dr. Spivey Douglass

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Dr. Xueping Li

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Accepted for the council:

Carolyn R. Hodges, Vice Provost and
Dean of the Graduate School

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A Methodology to Assess and Manage Material and Machine Tool Risks for a Manufacturer

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ashutosh Anil Hengle
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Abstract

Globalization and competition have forced manufacturers to analyze their processes to minute levels in order to improve the quality and on-time delivery of the product. Due to the increased complexity of manufacturing and the associated supply chain, a wide range of additional risk factors have been introduced that impact the manufacturing processes. A process that is constantly exposed to such risks may not be able to meet customer expectations such as the on-time delivery of products. Extensive research has been done on enhancing the capabilities of the manufacturing processes. However the focus of this effort is to develop a methodology to manage risks that have a high impact on the process lead time and will enhance the ability to sustain process performance. The purpose of this study is to identify key risks associated with manufacturing and develop a framework to assist manufacturers mitigate the risks resulting in increasing the manufacturing lead time. The framework takes on the format of an assessment that investigates the multiple risk dimensions associated with material and tooling. Inputs to the assessments are confidence interval of 95%. Finally a mathematical analysis using AHP is done for prioritization of risk mitigation activities. A case study is presented to the methodology.

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List of Abbreviations:

PERT – Program Evaluation and Review Technique

CPM – Critical Path Method

WIP – Work in Process

AHP – Analytical Hierarchal Process

SCM – Supply Chain Management

5S – Japanese term for Workplace Organization

Chapter 1

Introduction

1.1 Background

Contemporary manufacturers are under tremendous pressure of improving their performance in order to stay competitive in the rapidly expanding global economy. In order for a manufacturer to stay competitive, they have to explore all the possible ways to reduce cost and manufacturing lead time. A fundamental cause for most manufacturers' inability to constantly meet on-time delivery expectations is the risks associated with critical resources necessary to manufacture a product. Some of the most significant resources on the shop floor are materials and tooling. Unavailability of tooling material and tooling performance degradation has an adverse impact on the process lead time and subsequently the percent on-time delivery.

An example of material risk within supply chain is the fire in 2000 that destroyed electronic components in New Mexico required by Nokia and Eriksson. Eriksson's inability to manage the interruption in the supply chain resulted in direct lost sales estimated at $390M. Nokia on the other hand reacted promptly by securing existing components in the market providing a competitive edge to Nokia over Ericsson within the cell phone market. This example illustrates importance of monitoring and managing material risk [1] [2].

1.2 Risk

Risk can be denoted as a potential negative impact to some characteristic of value that may arise from a future event. It can also be defined as the events or conditions that may occur, whose occurrence has a harmful or negative effect". Exposure to the consequences of uncertainty constitutes a risk. In everyday usage, risk is often used synonymously with the probability of a known loss [20].

$$RISK = Pa * C$$

Where,

Pa = Probability of an accident

C = Consequence in lost money/resources.

Risk is the chance of something that will have an impact on objectives. A risk is often specified in terms of an event or circumstance and the consequences which may flow from it. It is measured in terms of a combination of the consequences of an event and their likelihood. It is important to deal with risk by addressing the following

1. Identify events leading to negative consequence
2. Estimate the probability of these events
3. Develop an exposure score to prioritize risk

1.2.1 Material Risk

Material risks often lead to substantial and visible consequences within the entire supply chain. The following are current examples of material risk. Boeing in 1997 lost $2.6B due to raw material and part shortages. In addition the 787 dreamliner is also expecting delays due to material issues. That same year, Toyota halted production for 20 days after single supplier location faced a fire accident [3]. VIC I Commercial Aircraft Co Ltd – The first Chinese-made commercial jet will delay its maiden flight by about six months because suppliers failed to deliver components on time. Development has cost six billion Yuan (US$853.6 million). Even cross-border issues, such as those that followed the WTC attacks, had an impact on the on-time delivery of products due to random inspections at customs and sudden border closure. This made the global supply chain more volatile and vulnerable. Long queues of trucks were seen at the US-Canadian border leaving many of the US automotive assembly plants starving for material. Thus, even the most successful production system strategies are prone to risks on operations when catastrophe hits [4].

1.2.2 Tool Risk

Tool risk is evident at the grass root level of any process. There have been several instances where tool failures or improper functionality have resulted in losses. The most significant visible impact for the tool industry was in the 1980s when US tool manufacturing industry faced a crucial drop in business which led to tool unavailability to local manufacturers. Apart from this major event, problems with machine tools are related to their efficiency and performance. A few visible examples are surface finish not meeting quality standards, irregular tool wear causing frequent tool change and improper cutting parameters resulting in scrap.

1.2.3 Process Risk

Risk denotes a potential negative impact to the performance of a process. The concept of risk is presented and articulated as probabilities of such events occurring and prioritized by the consequences of such events for possible outcomes. Globalization has amplified the probability and magnified the impact of the consequences of failures as outlined below,

•Increased inter-dependency amongst partners within the supply chain network

•Increased regulatory compliance imposed by partner's governmental entities on international trades laws

•Increased variability in demand and supply due to an increased number of local, regional and global economies

•Increased technological inventions shorten product lifecycle and increase inventory obsolescence.

•Increased customer expectations that can place manufacturers in direct competition based on quality, reliability, on-time delivery, order fill rates and overall service level efficiencies

•Increased inability to balance capacity in the supply network

•Increased probability of natural disasters, potential unrest and other external environmental events.

Dealing with all process based risk is beyond the scope of the study. This study will focus on material and tool based risk on manufacturing processes. Risk associated with materials has a complexity of adverse effect on the overall process effectiveness and efficiency. Another important element that is an integral part of any manufacturing process is the tools used to manufacture that product. Tools are as important as materials since the quality of the final product and the manufacturing time is also dependent on them. A framework that elaborates risk must be developed to quantify this risk [13][14][16].

1.3 Methodology Framework

There are varieties of ways in which organizations protect themselves from supplier delays, variations and risk within their supply chain. One extreme case is to duplicate supplier capabilities in-house. A vivid example is that of Boeing which uses time buffers for its projects to absorb any kind of delay caused by its suppliers. Project delays caused due to supplier variation are managed through ‘Emergent Manufacturing’ wherein a temporary factory is set up in-house to produce parts that are causing delays.

Risk Assessment is another aspect that has kept modern managers busy. Today’s fast paced business environment bombards organizations with a diverse array of risk events. Consequently, organizations are developing a variety of risk management strategies. In this environment, internal auditors have an opportunity to contribute to, or even drive, their clients' enterprise risk management activities. However, this opportunity brings new challenges. If auditors are expected to identify the organization's major risks, they need powerful diagnostic tools. Most traditional audit risk assessment models are too narrowly focused to encompass the full range of business risks. The diverse nature of these risks also creates measurement problems, because it is often difficult, or impractical, to quantify their time impact.

A more reasonable approach is to manage resources based on their impact on the project or on the most critical process. Analysis of a process can be done using project management tools such as PERT / CPM. These network planning techniques can lay an excellent foundation to commence any improvement process [38].

The study proposes a methodology as illustrated in figure 1.The flow chart in Figure 1 is a pictorial depiction of the methodology that is developed to address material and tooling risk in manufacturing processes. The methodology is based on multiple industrial engineering tools such as Operations Research, value stream mapping, AHP and project manager.

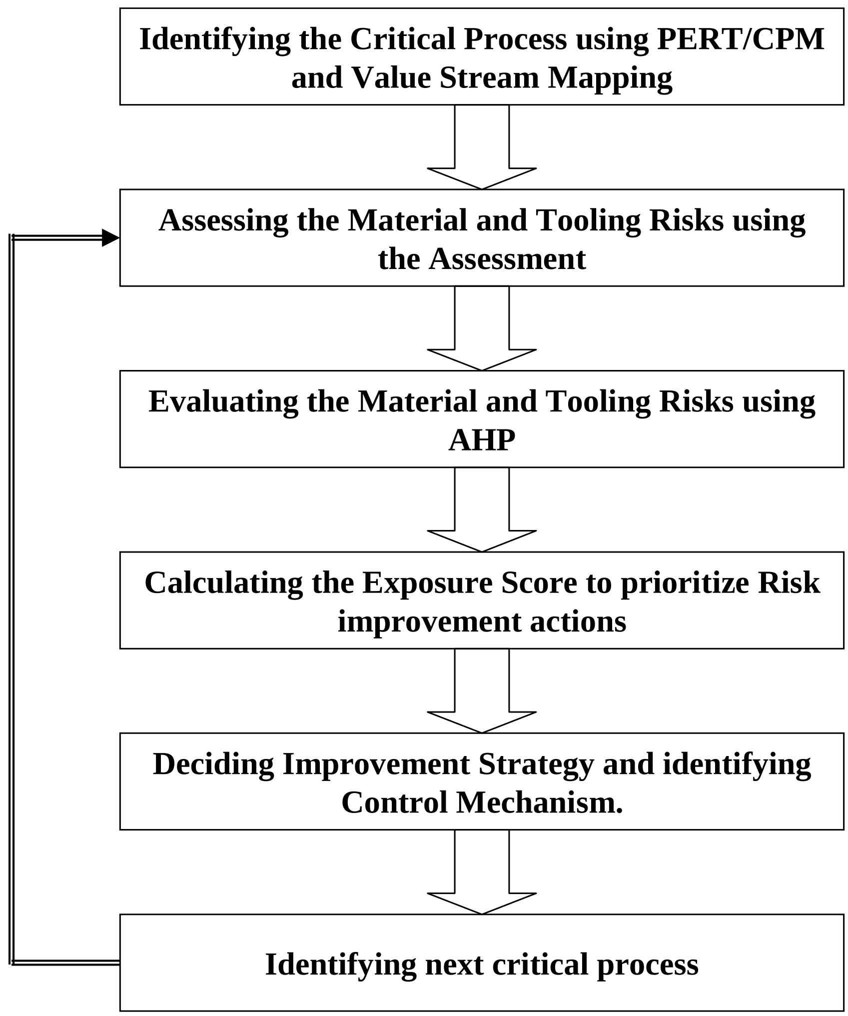


Figure 1 – Conceptual Framework

1.4 Organization of Thesis

This thesis is comprised of five chapters including this introductory chapter. Chapter 2, literature review, provides a comprehensive review of various risk management models that are employed and proposed for the present business structure. This chapter also stresses the need for developing a new risk assessment and management tool as the existing tools does not correspond to the growing uncertainty in a process. Chapter 3, research methodology details the methodology proposed in this study. A detailed description of developing a new framework and the sequence of steps involved in the process of the risk management function is delineated. Chapter 4, “Case Study and Results”, consists of the application of the methodology to a practical example from industry. Chapter 5, “Conclusion”, summarizes the major bindings of this study.

Chapter 2

Literature Review

2.1 Introduction

Chapter 2 illustrates the current work associated with managing risk within the manufacturing environment. The specific focus of this chapter is on the tools and techniques by which risk is managed in the current scenario. The literature review will focus on the following issues;

1. Risk classification.
2. Risk assessing techniques.
3. Risk management.

2.2 The Basic Risk Management Process

"Risk Management is the culture, process and structure that are directed towards realizing potential opportunities whilst managing adverse effects. The process of managing risk is a systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context for, identifying, analyzing, evaluating, treating, monitoring and reviewing risk." [43]. Figure 2 illustrates the risk management process in detail.

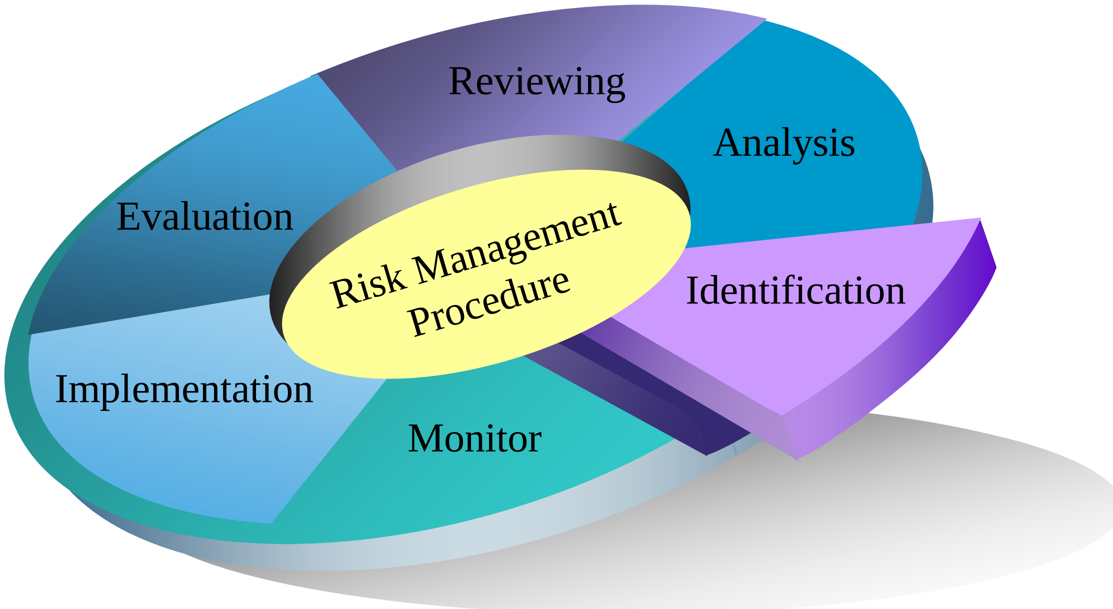


Figure 2 – Risk Management Process

The most crucial and preliminary step of the risk management process is Risk Identification. In this step the factors that have an adverse impact on the system are identified as risk inducing factors. The identified risk factors are then analyzed for its likelihood and failure consequences in the Risk Analysis step. This is followed by prioritizing the risks based on the impact of its consequence on the system in the Risk Review step. In the Risk Evaluation step the validity of the identified risk factors is evaluated. For factors that are identified as intolerable, appropriate actions are implemented in the Risk Implementation step. Finally, the implemented actions are continuously monitored in the Risk Monitoring step for sustaining the management process.

2.3 Introduction to Enterprise Risk Management

Enterprise Risk Management (ERM) is a means in the financial services industry for addressing credit and market risks. It is also used as a means of improving the performance of business operations. But overall industrial sectors have lagged behind in implementing a true enterprise wide view of risks. Business organizations are now recognizing that global sourcing and just-in-time lean manufacturing are making them vulnerable to new risks, local and global, though yielding significant cost savings. Enterprises are striving to achieve minimum inventory levels and efficient utilization of production capacity which have rendered the use of traditional buffers obsolete against disruptions. In response to this diverse scenario, business enterprises have started to improve their current capabilities in managing risks and alleviating the impact of possible disruptions. In this chapter we will discuss a few strategies that companies are using to identify and assess manufacturing and supply chain risks to improve their operational awareness and responsiveness to risk events.

The steps followed by companies to get started in identifying and assessing manufacturing and supply chain risks to improve their operational awareness and responsiveness to risk events are.

Step 1: Assemble a cross-functional team of process experts:

A diverse team of experts from across the organization is selected for a fast paced identification of risks in their areas. Team members can be Manufacturing Engineers, Statistical Analysts, IT experts, Supply Chain and Logistics Managers etc. From the group a core team of “risk evangelists” (source) should be formed to promote risk awareness within the organization, monitor the continuous improvement process and benchmark all achievements.

Step 2: Assemble all teams for Brainstorming sessions to identify the enterprise risks:

An organizational portfolio of risks is developed from the brainstorming exercise which is generally divided into four broad groups financial, operational, environmental and technical. This risk classification helps the managers and engineers to identify the risks that impact their responsibilities.

Step 3: Filtering and Prioritizing Risks for Assessment:

Depending on the range of impact and the probability of occurrence, the identified risks are prioritized to develop a risk map to commence the risk assessment process. Proper classification of risks into relevant categories can help the team to recognize the relative difference in terms of occurrence and severity.

Step 4: Commence Risk Management Process:

After identification, classification and prioritization of risks, concerned personnel begin to work on the actionable risks (risks whose impact can be alleviated). Using the Risk Mitigation tools, the Risk Management process makes the operations more resilient and responsive in a dynamic environment.

2.4 Enterprise Risk Management Models

Enterprise Risk Management has become increasingly sophisticated over the years due to the rapid changes in business procedures. The inter-dependency amongst the partners in the supply chain network has urged most enterprises to develop methods for identifying, assessing, managing, mitigating and controlling the impact of disruptive events. In response to this, researchers have proposed methods and models to alleviate the impacts of these disruptions. Some of the risk management models that are currently used for managing risks at the enterprise level are;

2.4.1 Reliability Models

Reliability models are widely used in military and technological environments where high reliability is expected. They are commonly used for estimating the probability that a system will be working at any given point of time. Reliability models consist of two stages namely reliability data collection and the fault and event tree analysis [9] [10] [11]. The data collection stage involves collecting data required for risk quantification. The fault and event tree analysis sage involves analyzing the risks in the form of a tree diagram which first shows the different outcomes of a specific event and also the combination of events that can lead to a specific event.

2.4.2. Deterministic Analytical Models

Deterministic models comprises of mathematical programming models (e.g. linear, nonlinear, integer, dynamic programming). The supply chain applications of these models include scheduling, distribution, MRP, facility location, managing inventory level and the replenishment strategy, order quantity specification, and resource balancing.

2.4.3. Stochastic Analytical Models

Stochastic models follow probability distribution principles wherein the outcome of at least one of the variables is uncertain. The supply chain applications of these models include inventory and production management, where demand and yield are represented as random variables respectively.

2.4.4. Economic Models

Economic models are focused on buyer-supplier relationships. These models have a traditional base in determining the financial risks to either sellers or buyers, given various assumptions.

2.4.5. Simulation Models

Simulation models are data driven representations facilitated by sampling from specified probability distributions.

2.5 Summary of Literature Review

This chapter provides a review of the risk management process and the models that are commonly used for managing risk at the enterprise level. However these models lack the ability to deal with the operational risks in a dynamic environment and also the variation in a process. The literature review suggests that a comprehensive study for risks associated with resources such as materials and machine tools is imperative. The following chapter discusses the methodology involved in assessing and managing material and machine tool risks in the manufacturing environment.

Chapter 3

Methodology

3.1 Introduction

A risk mitigation model is presented in this chapter. This model focuses on the process risks in terms of materials and machine tools. The model will assess measure, monitor and mitigate these risks to create a more reliable process tool. The model will focus on high impact factors as well as factors that may not be obvious to process improvement diagnostics.

The conceptual framework involves various types of risks to which an organization is prone to over time. The scope of the effort is focused on risks associated with materials and tools which impact the project lead time. Just broadly identifying the area/departments for improvement in an organization will not serve the purpose. It needs to be broken down further to better understand and deal with its components. Hence the risk associated with materials is split as, risk of material being not ***AVAILABLE***, risk of material not meeting ***QUALITY*** and risk of material not meeting ***SPECIFICATIONS***. Similarly the risk associated with tools is split as, risk of tools not being ***AVAILABLE***, risk of tool ***EFFICIENCY*** and risk of tool ***PERFORMANCE***.

3.2 Risk Breakdown Structure

The risk breakdown structure is delineated to define risks and classify risks into different groups and areas that comprise the operational domain of a company are addressed in this study.

1) Operational
2) Financial
3) Brand and Reputation
4) Legal
5) Environmental, and
6) Technical

Each of these areas can be further subdivided into Internal and External factors. Further distribution of risks is depicted in Figure 3. This study is aimed at risks associated with the internal resources of a firm namely Material and Tools. Risks associated with materials are evaluated with respect to their availability, quality and specifications. Similarly, the risks associated with tools are evaluated for availability, efficiency and performance (Figure 4).

3.2.1 Detailed Risk Breakdown Structure for Materials and Tools

A. Materials:

a. <u>Risk of Availability:</u> Smooth operations require that required materials are available whenever needed and in the designated amount. Disruptions and/or shortages may lead to halting of subsequent activities leading to delay and in some cases major monetary losses. An assessment is developed that provides a set of brief questions to ascertain the level of implementation of operations related to material availability.

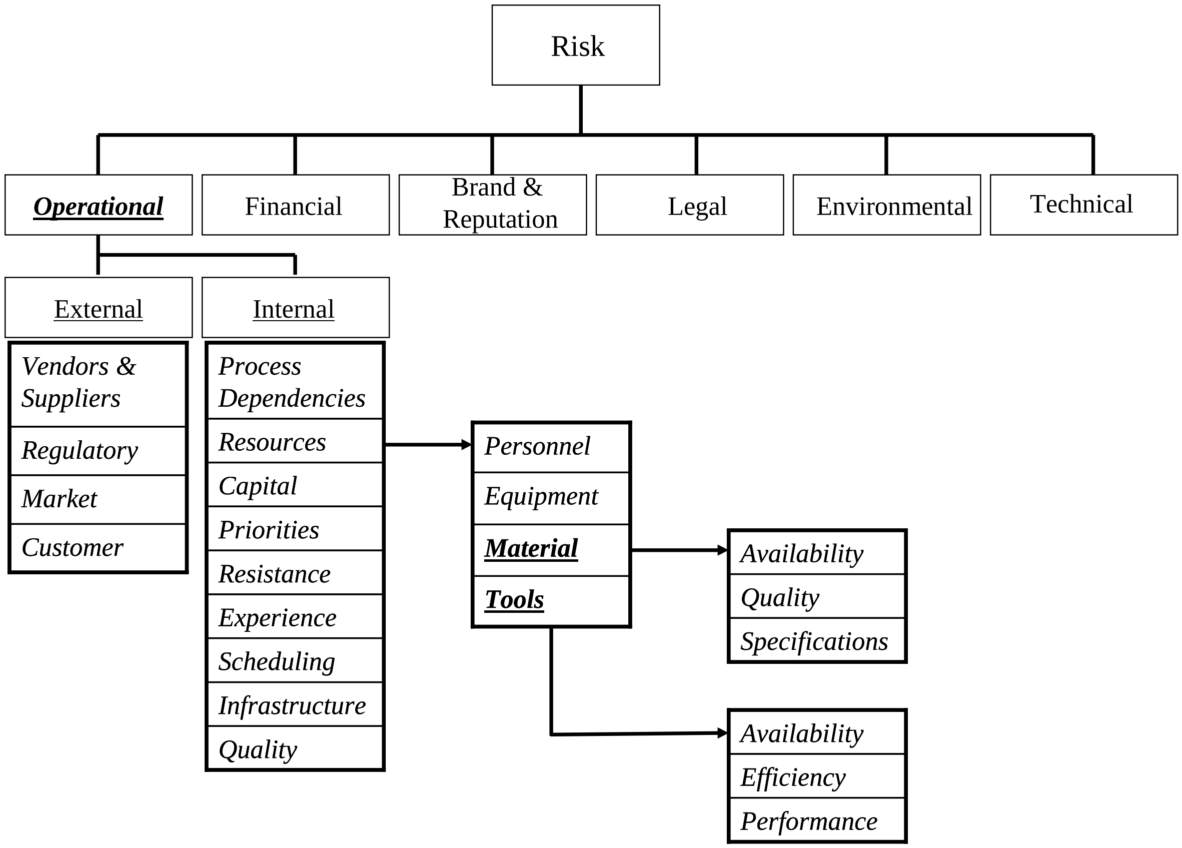


Figure 3 - Risk Breakdown Structure - 1

b.<u>Risk of Quality:</u> When the material is available the second most important thing is whether it meets the quality standards. No organization can compromise on quality since it affects their reputation and may also lead to loss of potential customers. The assessment contains a set of brief questions to ascertain status of the factors that can impact material quality are in place.

c.<u>Risk of Specifications:</u> After ensuring the material quality, it is imperative to confirm whether the material meets the specifications of design in order to ascertain its manufacturability. The assessment provides a set of brief questions to ascertain the systems that specify the material are efficient.

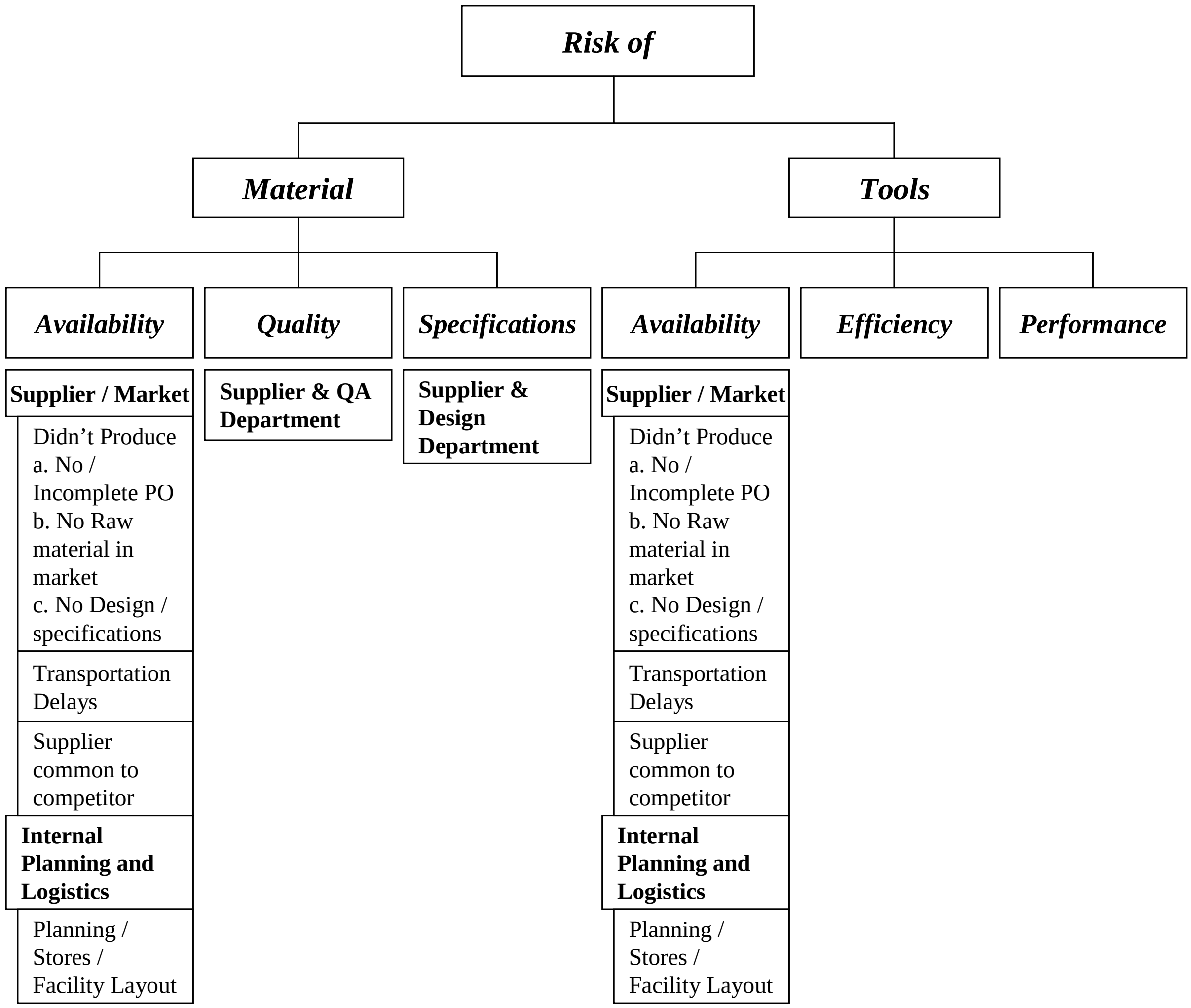


Figure 4 - Risk Breakdown Structure - 2

B. Machine Tools:

a. <u>Risk of Availability:</u> The requirements of material availability are also applicable for machine tools availability. It is very important that the required tool is available whenever needed. Tool shortages can delay the supply of commodities to the end user, may lead to halting of subsequent activities and in some cases major monetary losses. The assessment provides a set of brief questions to ascertain all the processes related to machine tools availability are in place. An inventory management system can be incorporated to ensure proper availability of tools.

b. Risk of Efficiency: A machine tool is expected to have good efficiency, which means each and every time when the tool is put into use, it should give the desired yield and be also reliable. The factors that affect tool efficiency are;

i. Tool and Work piece Material
ii. Cutting Parameters (Spindle Speed, Feed and Depth of cut)
iii. Use of correct cutting fluids while machining
iv. Mechanically correct tool holders, collets and chucks
v. Right tool maintenance when not in use

The assessment provides a set of brief questions to ascertain that the above factors that impact the tool efficiency are as per design.

c. Risk of Performance: Tools are generally judged on their performance on machines. The performance criteria are

i. Ability to produce desired shape and size
ii. Produces with required accuracy and surface finish
iii. Simple in design and easy in operation and maintenance
iv. Aesthetically and Ergonomically good
v. Low cost of manufacturing and operation

The assessment provides a set of brief questions to ascertain all the systems related to machine tools performance are functioning well. This includes support functions like right tool selection and proper maintenance.

3.3 Methodology

The Methodology consists of mapping the entire process using PERT method and identifying the critical processes using CPM technique. The critical processes are then evaluated for effect of Tools and Materials using Analytical Hierarchy Process (AHP) and risk exposure scores for each of the critical processes are evaluated so as to determine the improvement strategy that needs to be employed / suggested. The methodology is demonstrated in the form of a flowchart in Figure 5. Each block is elaborated in the subsequent sections.`

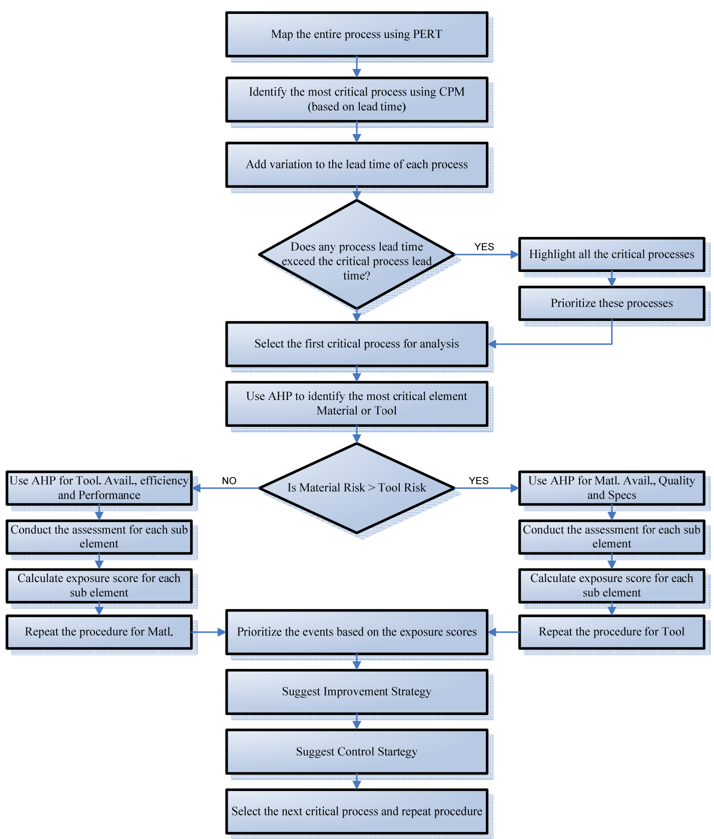


Figure 5 - Methodology

3.3.1 Define: Identifying the Leverage point:

First we identify the process that is the most significant for the organization and we term it as the leverage point since the significance of each of the six risk components will differ from process to process. So before prioritizing them, it is essential to identify the most critical process. CPM/PERT analysis along with value stream mapping will be used for this procedure. A sample assembly process is shown below to better explain the step. Here a process implemented by a manufacturer is used as an example wherein parts processed by six different processes are assembled. Table 1 gives the lead time of each individual activity.

Step 1:

All the activities are drawn in a network diagram explicitly showing the preceding and the succeeding activities and the interdependency between them. Figure 6 illustrates the PERT diagram which helps to analyze and represent activities in a given process. The network diagram can then be used to identify preceding and succeeding activities, their lead times and can be useful for scheduling purposes.

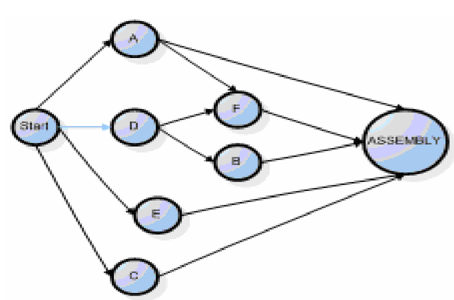


Figure 6 - PERT Network

Step 2: Possible Paths

All the processing routes are tabulated in this step (Table 2). These are nothing but a series of events that have a common end but the paths vary. The same PERT network is used for this, the difference being that all possible chain of events that start from the first activity and end with the last are identified and highlighted for better understanding of the entire process.

Step 3: Critical Path

Among these paths, one or maybe more than one has the longest finishing time (Table 3). The critical path method (CPM) is used in this step. CPM calculates the longest path of planned activities to the end of the project, and the earliest and latest that each activity can start and finish without making the project longer [20]. It identifies the activities that are "critical". Those paths are identified in this step.

Step 4: Overall Project Completion Time

There is always some variation associated with any activity. To amount for this an initial buffer is considered which will compensate for any variation in the process. Adding buffer adds on to the project completion time and in this step the revised lead time is calculated based on the buffer level (Table 4, assuming 5% buffer for each process).

Step 5:

Sometimes there is a possibility that the activities might utilize more time to complete due to variations. If these activity times happen to exceed the critical process time, it will change the critical path. If anticipated, these activities can be managed accordingly. Variation is added to each activity and the revised lead time is calculated (Table 5).

<u>Step 6:</u>

After adding variation to each individual activity, it may be observed that high variations may have caused few activities to exceed the critical process time. In this step, processes that may exceed the minimum process completion time of the pacemaker are identified. These processes can become the potential bottlenecks (Table 6).

<u>Step 7:</u>

All the activities that may exceed the critical process time are identified. This step is significant since it shifts the focus from critical path to critical activity. This in return will help for better scheduling and allocation of resources depending on the scenario. The possible critical paths are identified in this step (Table 7).

Table 1 – Process Times

Process	**Process Time (units)**
A	13.4
B	15.1
C	16.6
D	16.1
E	10
F	11
Assembly	10

Table 2 – Possible Paths

Path	Activities	Duration
P1	A- Assembly	23.4
P2	A - F - Assembly	34.4
P3	D - F -Assembly	37.1
P4	D - B - Assembly	41.2
P5	E -Assembly	20
P6	C - Assembly	26.6

Table 3 – Critical Path

Path	Activities	Duration
P1	A- Assembly	23.4
P2	A - F - Assembly	34.4
P3	D - F -Assembly	37.1
P4	D - B - Assembly	41.2
P5	E -Assembly	20
P6	C - Assembly	26.6

Table 4 – Overall Project Completion Time

Path	Time
P1	24.57
P2	36.12
P3	38.95
P4	43.26
P5	21
P6	27.93

Table 5 – Project Completion Time with Variance

Project Completion Time due to Variation					
Path	+5%	+10%	+15%	+20%	+25%
P1	25.7985	27.027	28.2555	29.484	30.7125
P2	37.926	39.732	41.538	43.344	45.15
P3	40.8975	42.845	44.7925	46.74	48.6875
P4	45.423	47.586	49.749	51.912	54.075
P5	22.05	23.1	24.15	25.2	26.25
P6	29.3265	30.723	32.1195	33.516	34.9125

Table 6 – Processes exceeding Critical Time

Project Completion Time due to Variation					
Path	+5%	+10%	+15%	+20%	+25%
P1	25.7985	27.027	28.2555	29.484	30.7125
P2	37.926	39.732	41.538	43.344	45.15
P3	40.8975	42.845	44.7925	46.74	48.6875
P4	45.423	47.586	49.749	51.912	54.075
P5	22.05	23.1	24.15	25.2	26.25
P6	29.3265	30.723	32.1195	33.516	34.9125

Table 7 – Potential Critical Processes

Project Completion Time due to Variation					
Path	+5%	+10%	+15%	+20%	+25%
P1	25.7985	27.027	28.2555	29.484	30.7125
P2	37.926	39.732	41.538	43.344	45.15
P3	40.8975	42.845	44.7925	46.74	48.6875
P4	45.423	47.586	49.749	51.912	54.075
P5	22.05	23.1	24.15	25.2	26.25
P6	29.3265	30.723	32.1195	33.516	34.9125

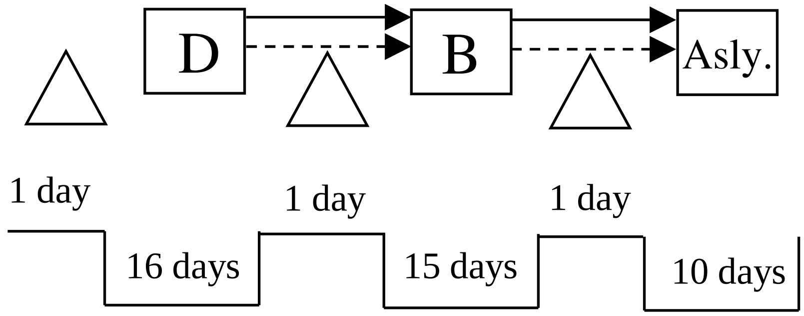


Figure 7 - Value Stream Map

Step 8:

Value Stream Map (VSM) is a technique used to analyze the flow of materials and information currently required to bring a product or service to a consumer. Figure 7 shows a value stream map where the most critical path is value stream mapped to simplify the process identification step.

Step 9:

After value stream mapping the critical path, it is essential to identify the pacemaker with which we will be commencing our kaizen events. The leverage point is identified in Figure 8.

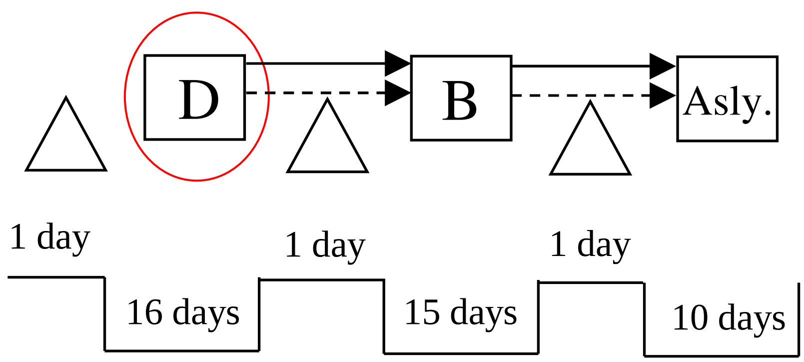


Figure 8- Value Stream Map with Leverage Point

After identifying the leverage point, the six risk components are given preferences (weights) based on its significance to the selected process in comparison to each other. It follows the assessment which is designed separately for each of the risk component.

3.3.2 Measure: Risk Evaluation Assessment:

Purpose:

1. To assess all activities within manufacturing periodically;
2. To assess everything that affects manufacturing process, but not at once
3. To use methods that shop floor personnel are familiar with: *e.g.*, if the discipline does not use statistical analysis, descriptive studies may be appropriate.
4. To focus major assessment efforts upon those:

   a. What is most important to find out that impacts manufacturing process?
   b. What do you really want to learn to improve the process?

5. To build an assessment plan to provide the best data that the department can use
6. To use it as a kaizen event.
7. To encourage shop floor personnel to use assessment research for making the working environment more comfortable.

Working of the Assessment:

1. The assessment is in the form of a questionnaire (please refer Appendix 1) to be answered as either yes or no (Objective type).
2. For every sub-category (key-area identified in the Risk Breakdown Structure-Detail), only one person from each shift will conduct the assessment periodically.

3. Observations that are related with the machine or near the machine should be conducted by the machine operator
4. All other observations should be done by the respective supervisor of the selected area or the person responsible for that activity.
5. The assessment will give a final score for each sub-category based on the weights (calculated using AHP) and the observations from the assessment (%no).
6. Based on in which range (as shown below in Table 8) the score falls, priority can be given for that improvement activity.

3.3.3 Analyze

The analysis will be done in a two step procedure. First, Analytical Hierarchical Process (AHP) will be used to determine the weights/significance of each component of the assessment. Later the scores obtained from the assessment will be used along with the weights to determine to what risk the process is most prone. The entire process is described below in Figure 9.

Table 8 – Range

Range	Impact	Priority
>0.1	Severe	1
0.05-0.1	High	2
0.01-0.05	Medium	3
0.001-0.01	Low	4
<0.001	Negligible	5

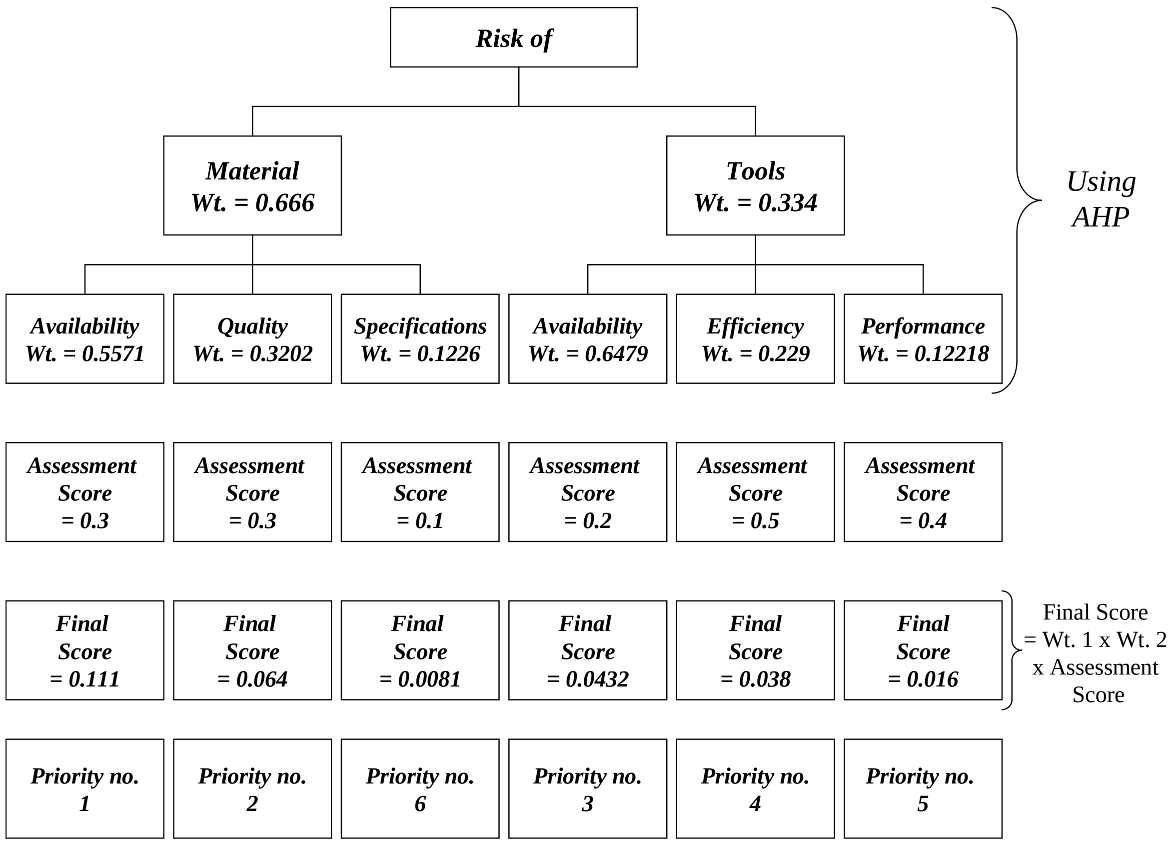
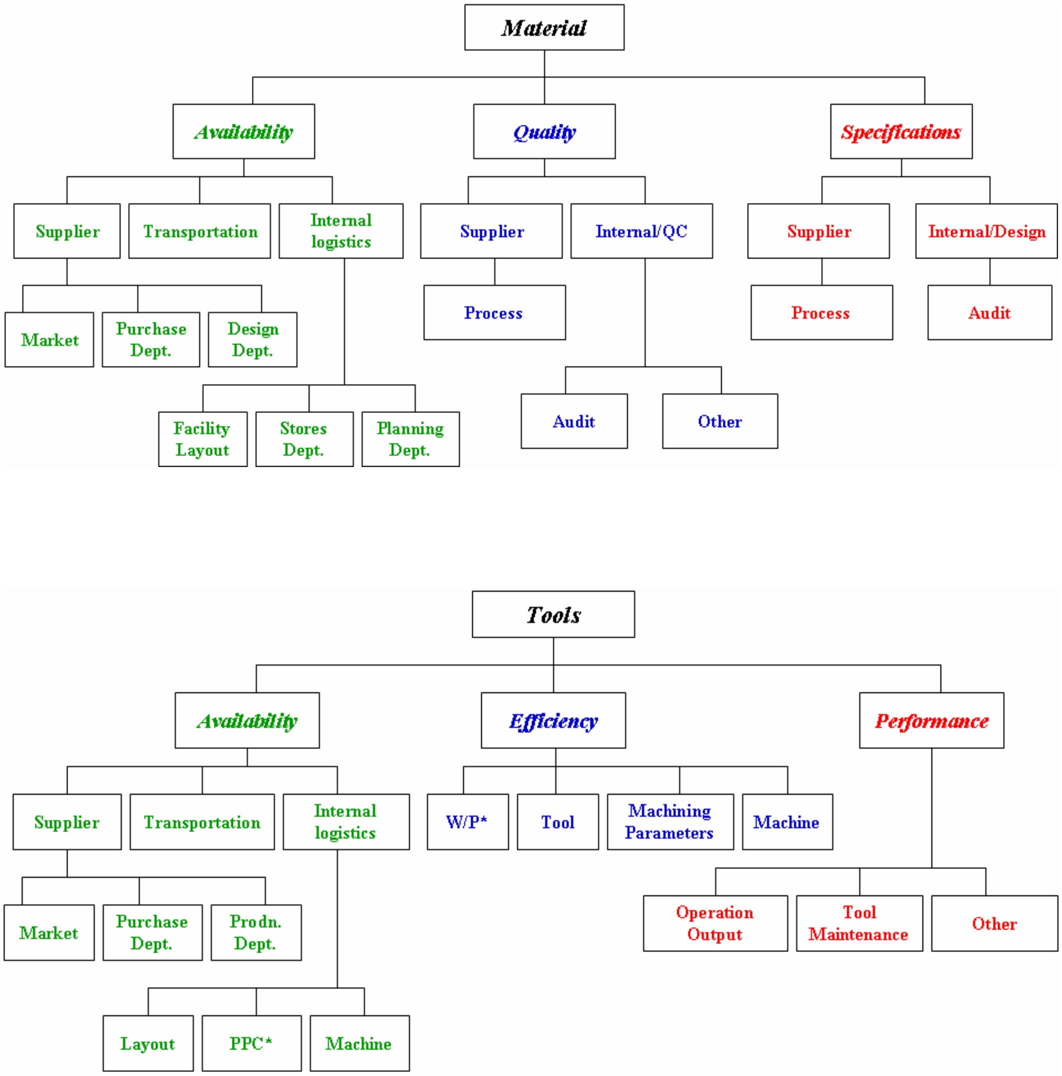


Figure 9 - AHP Procedure - Broad

The AHP procedure for the sample study is shown in Appendix 2. The AHP procedure helps to identify the most important factor for the selected process. Accordingly weights are assigned to each factor depending on their relevance to the process and significance over other factors.

The above analysis doesn't give us the more diversified approach that we want to achieve in order to minimize the number of improvement actions. To achieve this, the risk breakdown structure can be further classified as shown in Figure 10. The AHP and score calculation are done for the case study by using the following structure.



*PPC – Production Planning and Control; W/P – Work Piece

Figure 10 - Risk Breakdown Structure - Detail

3.3.4 Improve

After identifying the risk to which the process is most prone, the same assessment can be used to identify areas for improvement in order to alleviate the impact of the posed risk. A proper step by step improvement procedure can be followed as described below.

Phase 1: Risk Anticipation and Planning

The planning phase is one of the most important sessions despite the fact that it is preliminary to the acquisition of tools. This phase begins with the supposition that the organization will decide where the process currently is and where it wants to go and that it is now time to begin determining just how to get from one point to the other. Focus is on techniques for rapid implementation and allocation of responsibilities.

Phase 2: Developing a Infrastructure

From the outset of any journey, three pieces of information are of paramount importance. Those are, where is the process now, where does it want to be and how to get there? Content includes evaluating existing system for available resources and emphasis is also placed on identifying core competencies within and outside the organization and its associated tools like determining capacity requirements and establishing personnel requirements for the process.

Phase 3: Standardization and Support functions.

Standardization is one of the preliminary steps necessary for any program to succeed. It should be further noted that standardization does not apply only to typical procedures. Every activity should be planned in a similar/standardized way for every process to achieve an order in the implementation process. Also it will be simpler to design the support functions.

Support functions typically account for over 20% of overall labor expenditures in industry. The first step in streamlining support functions is changing the often rigidly held belief among those individuals working in supportive capacity that improvement techniques apply only to the production environment. Upon achieving this culture, support functions must then be identified and grouped into similar families. These activities may then be approached just as production processes with a series of kaizen events.

3.3.5 Control

To sustain the implemented system it is necessary to monitor it periodically or as scheduled. The success of any implementation rests on how long it can sustain itself. After the improvement process, the same assessment can be used to monitor the process over periods in order to keep the risk level under control.

Chapter 4

Case Study

4.1 Background

As discussed in the previous chapter, current business trends are becoming more complex and dynamic. This has increased the fragility for mitigating risks and also introduced new set of risks that needs to be addressed and managed. Before globalization, when most of the manufacturing was in-house and the suppliers were local, the risk was not so subtle and was easier to manage. With increasing complexity due to outsourcing, the risk associated with each process is increasing. As per Clemons, 2000, managers need to identify and manage risks from a more diverse range of resources and contexts. Unfortunately there is no such proactive model that can minimize the circumstances for risk. All models that are used by industries are reactive which follows the basic Risk Management process to mitigate the impact of risk.

Thinking about this a bit more, it becomes apparent that it is no easy job to develop a complete list of events which can characterize the future in enough detail to cover all outcomes, without becoming manageable. It is also important to think through how you will distinguish between the events themselves and their consequences. It will probably be useful to bring in concepts such as cause and effect, source and category and so on. In practice the uncertain future is by itself a long chain of cause and effect.

Industries are presently using a reactive approach to the problems they face. Investments are done to overcome a scenario rather than to prevent it. Researchers are spending lot of time to minimize the ill effects associated with the current volatile supply chain [22] [23] [24] [29] [30].

4.2 Supply Chain Management Models

The advent of supply chain models can be accredited to Wassily Leontief (1905-1999) who started with a simple input / output model, which has often been used to study national economies and regional economies within a country. This model shows the exchange of goods and services among industries and how finished goods flow to the customers or buyers. In essence the simplest form of supply chain representation.

Researchers and academics both agree that supply chain management (SCM) refer to a set of networked organizations working together to source, produce, and distribute products and services to the customer. Supply chain systems maximize profit by efficiently integrating and managing the flow of materials and information through different stages of manufacturing, transportation, and distribution and finally to the customer, refer Figure 11 and 12.

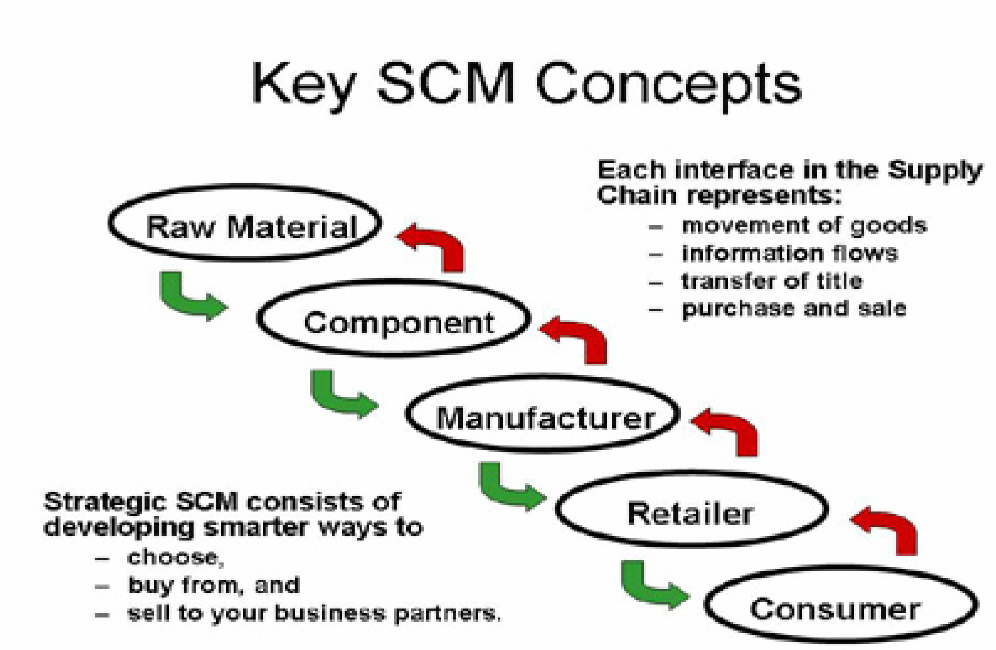


Figure 21 - A Simple Supply Chain Model [44]

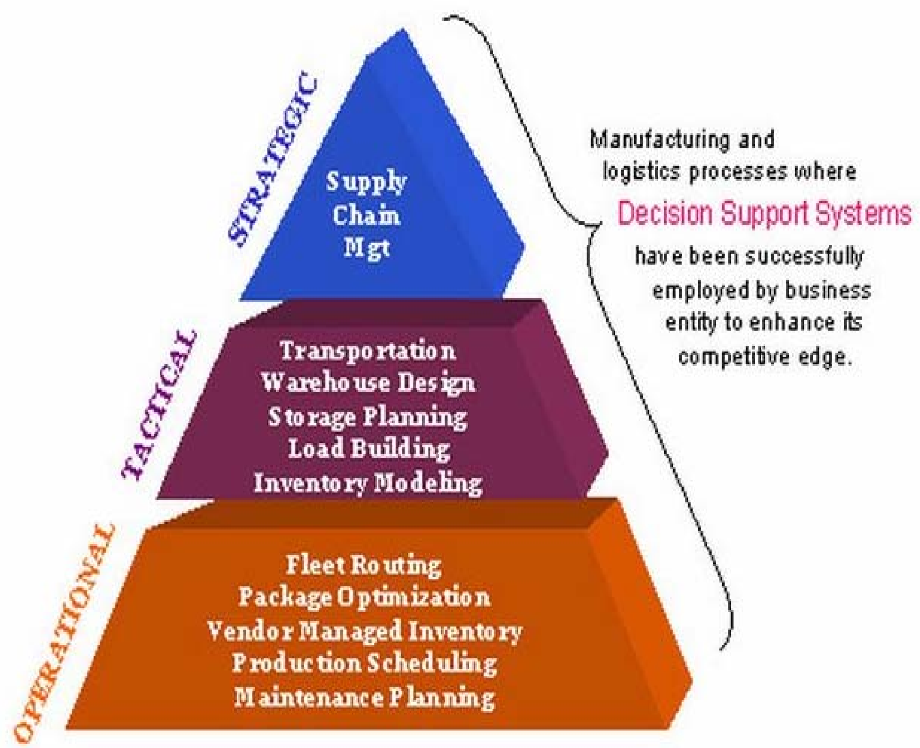


Figure 32 - Supply Chain Variables

As discussed in chapter one, the biggest challenge Risk management faces is the inaccuracy in predicting risks and strategies that are specifically designed to manage or mitigate risks. Strategist and engineers tend to use general MRP models to run their production systems and optimize their supply chains. Engineers and analysts often have created systems specifically tailored to their facility. For example, LOGSIM is a tool for managing the internal supply chain network of NOKIA. Its engine is designed with PROMODEL and the graphic interface with a visual basic editor. Another example is Compaq's supply chain management using the CSAT tool, the CSAT is an irrational supply chain simulator as it is designed only for Compaq's supply chain network and only uses the model of Compaq's internal logic [17][18].

Enterprises have tremendous research and strategies on customer satisfaction but little has been done to understand the uncertain variables and stochastic nature of the supply chain, there is also lack of complex and comprehensive models of the supply chain. Analytical models are unable to handle the dynamically changing supply chain variables. Simulation models on the other hand are known as the most efficient method for dealing with stochastic variables within the supply chain.

Ingalls further discusses why would one want to use simulation methodology to evaluate supply chain and what are its advantages and disadvantages. He compares them with other methodologies such as optimization, business scenarios etc. There is also research that has looked into the discrete event simulation Vs an event driven approach and system dynamics.

4.3 Description of the Case Study

The case study deals with a process within a tube bending company located in Knoxville, Tennessee. Due to the high volume of orders, customer inconsistency and equipment capabilities, scheduling of work orders is a tedious process. Also the equipment and system capability is challenged due to strenuous setups and product variety. Due to this, the prime focus is given on production which makes materials and machine tools utilization very important. This scenario exposes the system to risks of failures and disruptions due to material and tools failures that may hamper or directly impact the business. A detailed analysis of the existing process was important to figure out a list of 'to do' activities to anticipate any disruptions and save time and resources to overcome them later.

The process consists of five different sub-processes viz. cutting, bending, welding, washing and packing. As per the methodology it is essential to know the process times of each operation. A detailed assessment followed to identify the potential risks and necessary actions to be taken. Table 9 enlists the mean process times for each individual operation to begin with.

4.4 Methodology

Since we have already identified / defined the areas for study and improvement, we will commence the case study from the second step of the methodology, which is Measure.

4.4.1 Measure

A. Identifying the Leverage point

Step 1: Map the process as a PERT network diagram

In this step the overall process is mapped as a PERT network diagram depicting the operations of the firm (Figure 13).

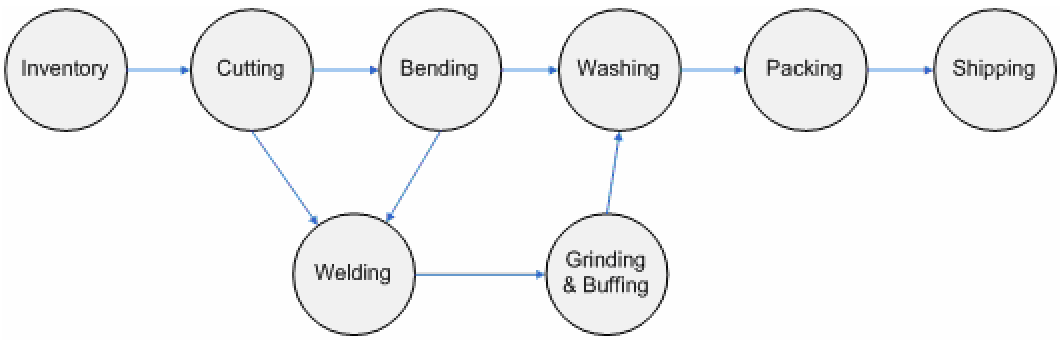


Figure 13 - PERT Model of Case-Study

Step 2: Identify all possible paths

In this step all the possible paths in the process are identified and the duration of the paths is calculated. The path duration is calculated as the sum of the lead time of the individual processes (Figure 14) (Table 10).

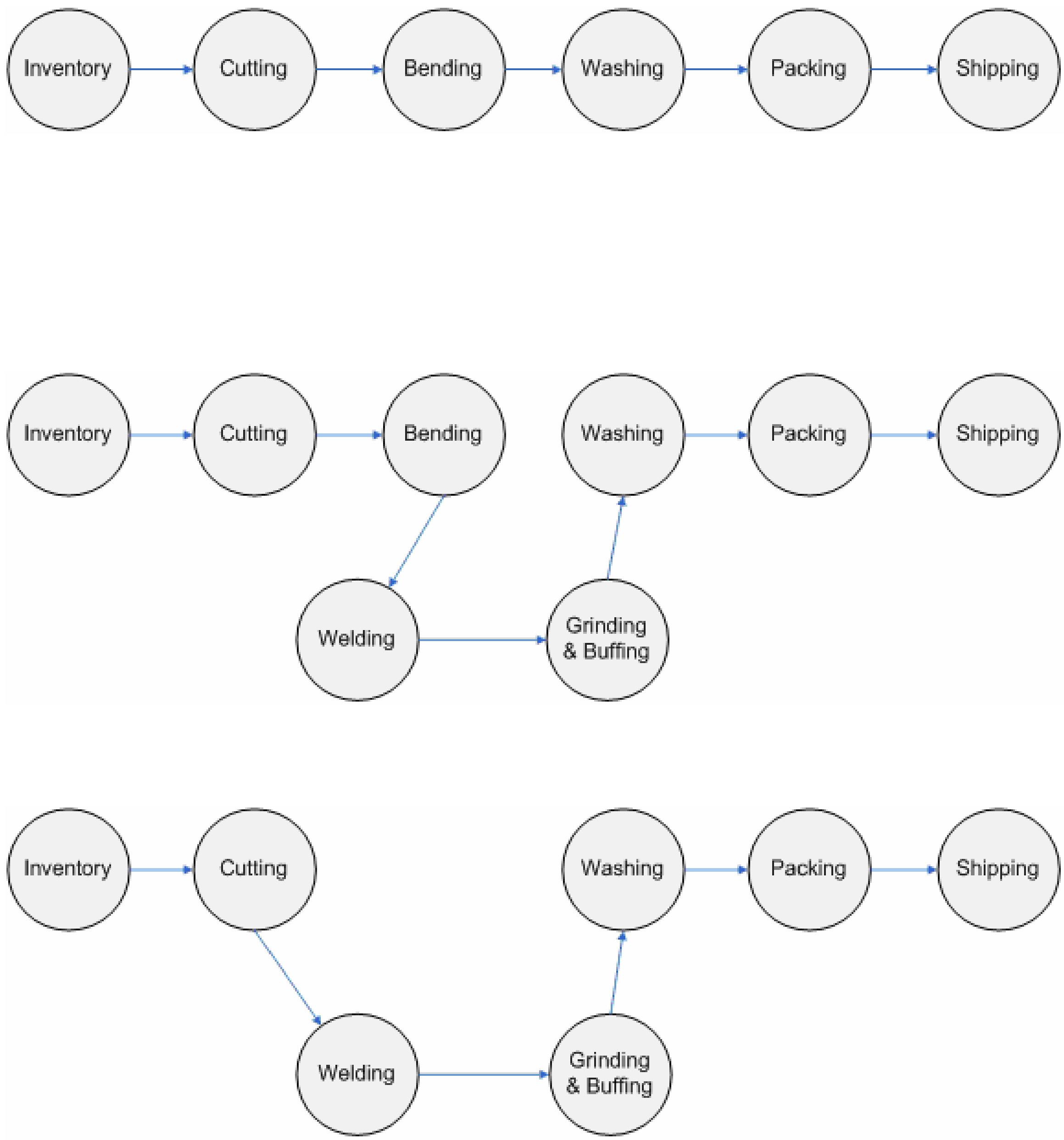


Figure 14 – Identified Critical Paths of Case-Study

Step 3: Identify the critical path

The path with the highest duration time is identified as the critical path in this step (Figure 15) (Table 11).

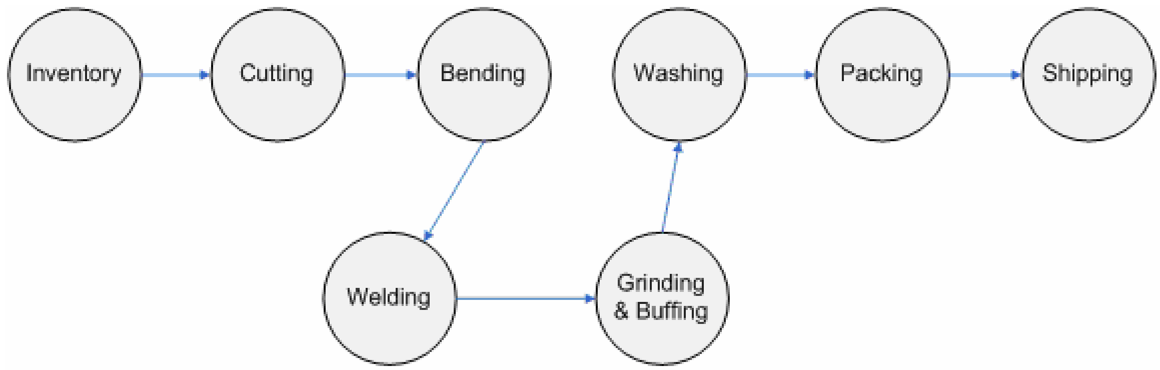


Figure 15 - The Most Critical Path

Step 4: Determine the overall project completion time

Adding buffer increases the project completion time and in this step the revised lead time is calculated based on the buffer level (assuming 5% buffer for each process) (Table 12).

Step5 : Add variation to the sub-activities and determine the estimated completion time of the activities and calculate the new path durations

The sub-processes of all the activities are analyzed by adding variation to it. The critical path of the sub-processes is identified in this step. The new path duration is calculated by summing the duration of the activities under uncertainty. The buffer times are not added to this duration (Table 13).

Step 6: Identify paths that exceed the overall project completion time

In this step, paths that exceed the overall project completion time are identified (Table 14).

Step 7: Identify the new critical paths

In this step the new critical paths are identified (Table 15).

Table 9 – Process Times for Case-Study

Process	Process Time (Mean hours)
Cutting	0.5
Bending	1.5
Welding	4.5
Grinding/Buffing	1.5
Washing	0.25
Packing	0.5
Shipping/Loading	0.5

Table 10 – Possible Process Paths

Path	Activities	Duration (hours)
P1	Cutting-Bending-Washing-Packing-Loading	3.25
P2	Cutting-Welding-Grinding-Washing-Packing-Loading	7.75
P3	Cutting-Bending-Welding-Grinding-Washing-Packing-Loading	9.25

Table 11 – Identifying the Process Completion Time

Path	Activities	Duration
P1	Cutting-Bending-Washing-Packing-Loading	3.25
P2	Cutting-Welding-Washing-Packing-Loading	7.75
P3	Cutting-Bending-Welding-Washing-Packing-Loading	9.25

Table 12 – Identifying the Critical Process with Buffer

Path	Duration
P1	3.41
P2	8.14
P3	9.7

Table 13 – Adding Variation to Process Times

Project Completion Time due to Variation					
Path	+5%	+10%	+15%	+20%	+25%
P1	3.5805	3.751	3.9215	4.092	4.2625
P2	8.547	8.954	9.361	9.768	10.175
P3	10.185	10.67	11.155	11.64	12.125

Table 14 – Identifying Processes that exceed Critical Process Time

Project Completion Time due to Variation					
Path	+5%	+10%	+15%	+20%	+25%
P1	3.5805	3.751	3.9215	4.092	4.2625
P2	8.547	8.954	9.361	9.768	10.175
P3	10.185	10.67	11.155	11.64	12.125

Table 15 – Identifying Potential Critical Processes

Project Completion Time due to Variation					
Path	+5%	+10%	+15%	+20%	+25%
P1	3.5805	3.751	3.9215	4.092	4.2625
P2	8.547	8.954	9.361	9.768	10.175
P3	10.185	10.67	11.155	11.64	12.125

Step 8: Value Stream Map the most critical path

Figure 16 details the value stream map of the critical path in the system.

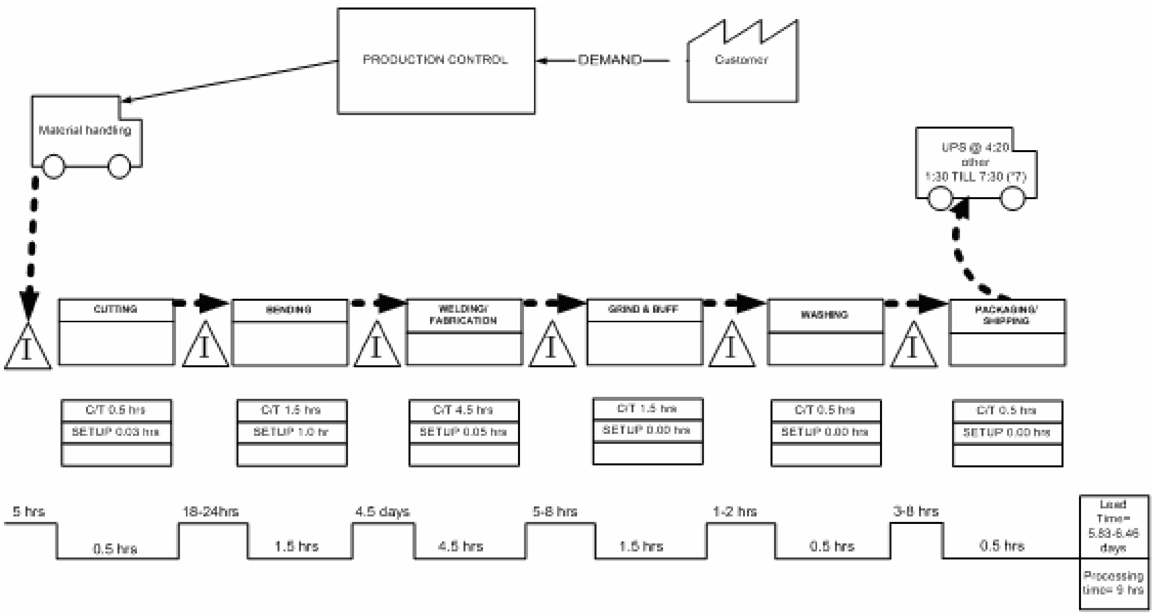


Figure 4 - Value Stream Map of the Critical Path

Step 9: Identify the Leverage point

Figure 17 identifies the leverage point in the critical path of value stream map.

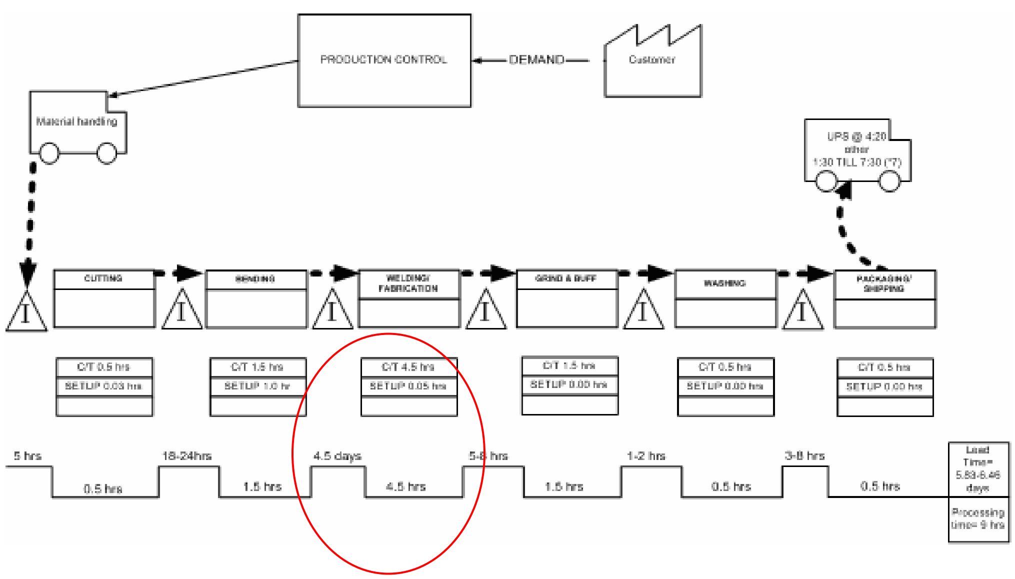


Figure 17 – Value Stream Map of the Critical Path with Leverage Point

B. Risk Evaluation Assessment: (Please refer Appendix 1)

From the part 'A' of measure we concluded that the welding process is the most critical one and has the most impact on the capability of the process. It is very important that proper resource management should be in place for this process.

The assessment was conducted for the selected process and the results are analyzed below.

4.4.2 Analyze

From AHP we determined that the most critical resource for the welding process is it tools as compared to materials. The analysis is shown in Figures 18 thru 22.

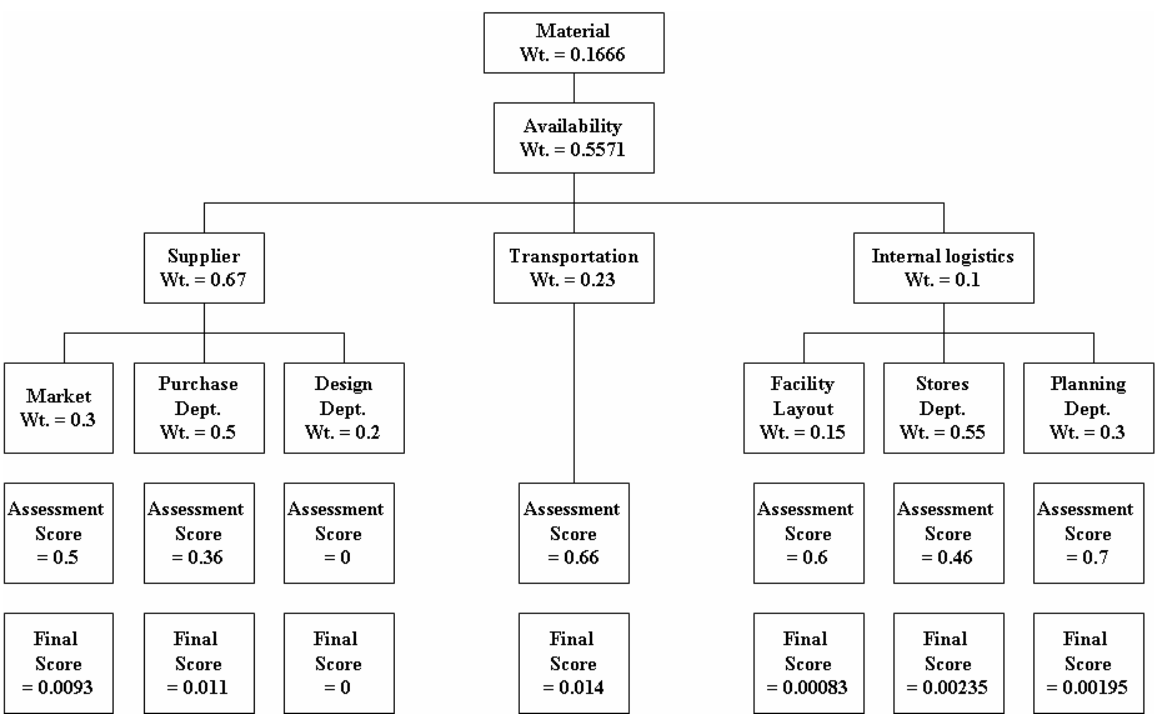


Figure 18- Extended AHP Procedure: Material Availability

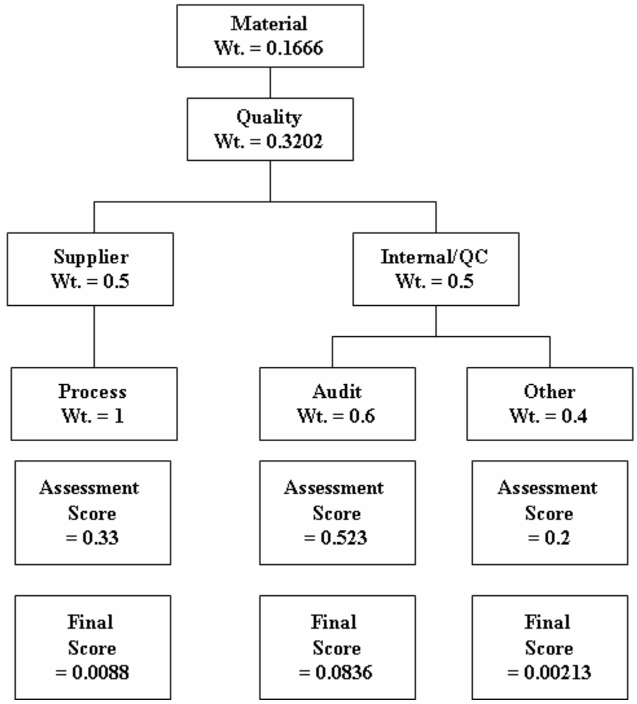


Figure 59 - Extended AHP Procedure: Material Quality

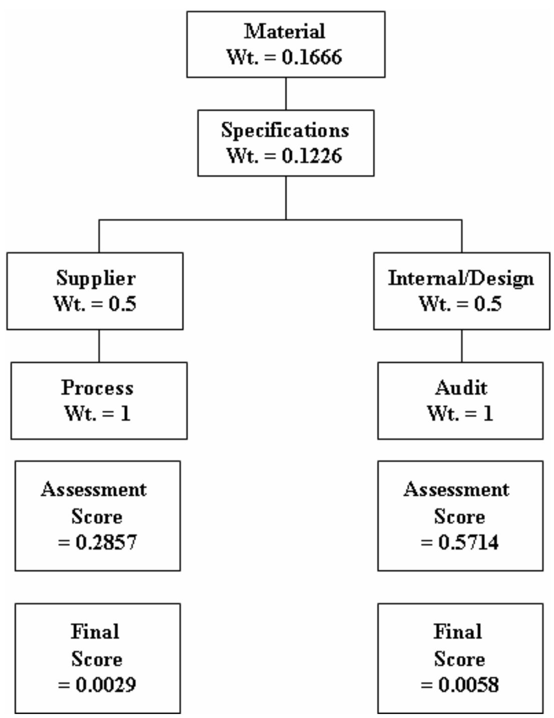


Figure 20 - Extended AHP Procedure: Material Specifications

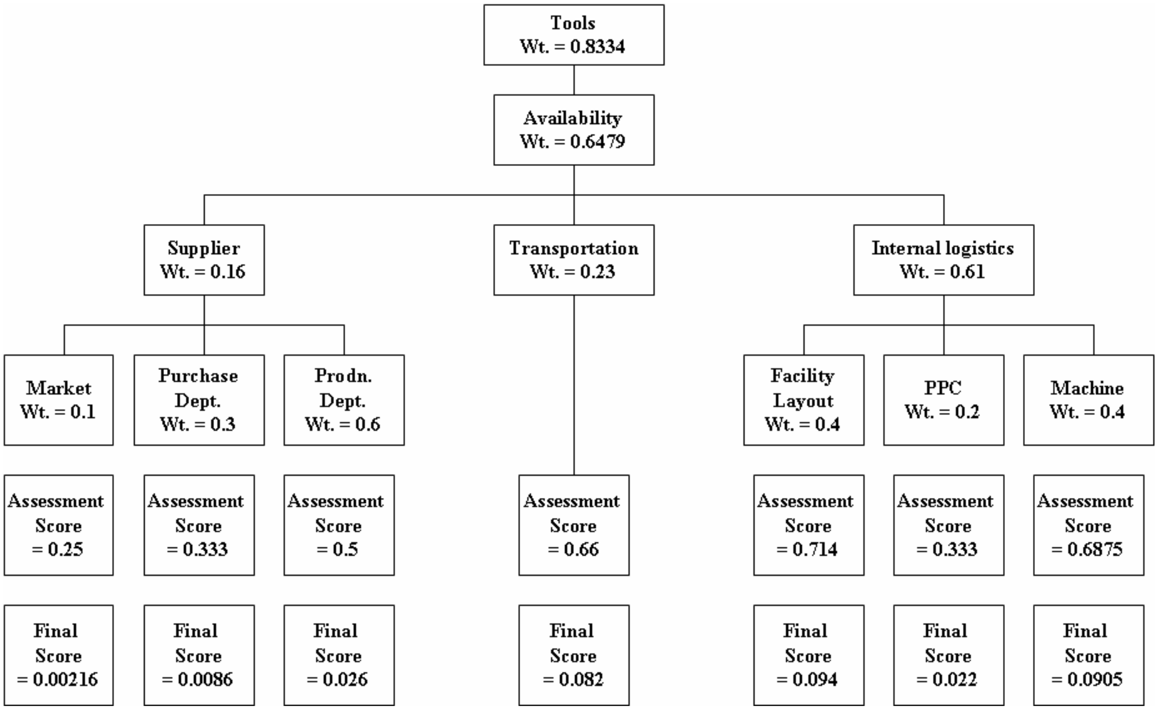


Figure 21 - Extended AHP Procedure: Tool Availability

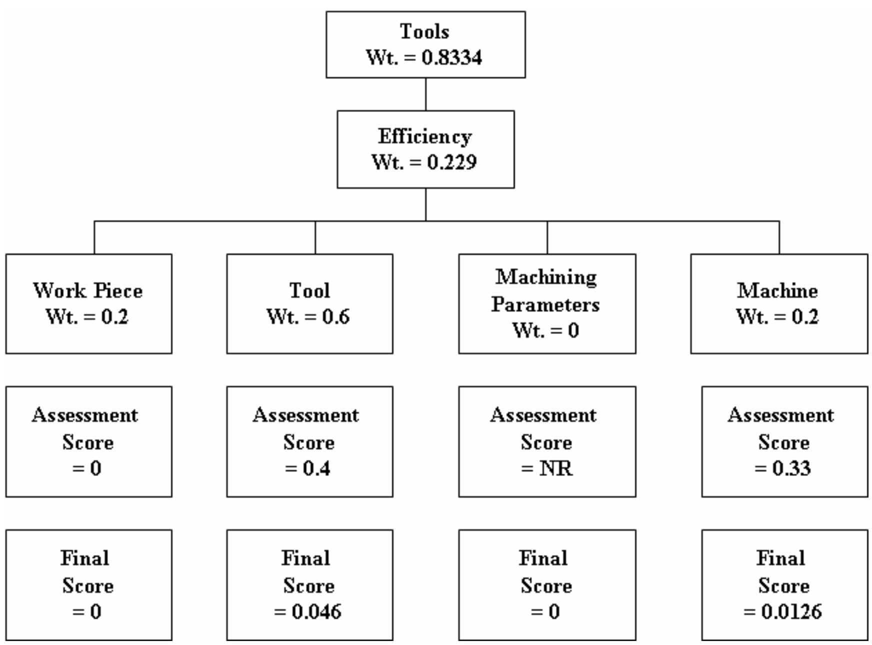


Figure 22 - Extended AHP Procedure: Tool Efficiency

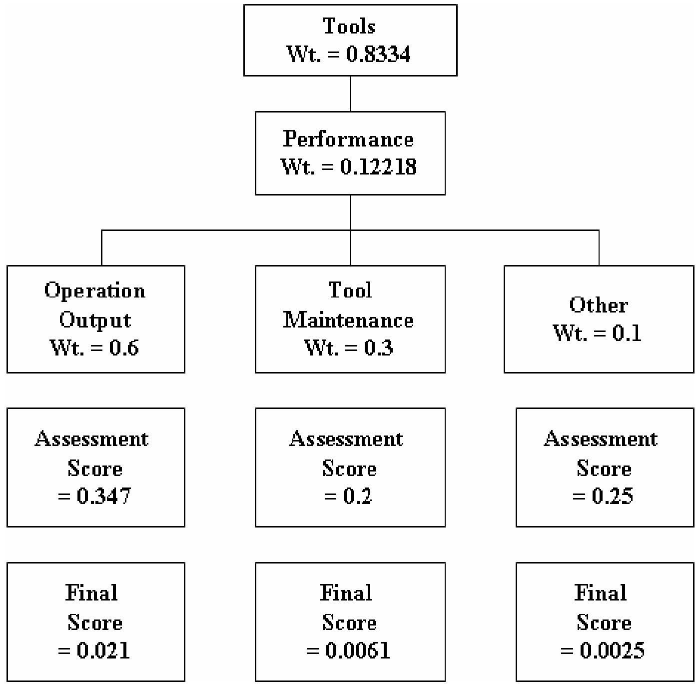


Figure 23 - Extended AHP Procedure: Tool Performance

Table 16 – Range

Range	Impact	Priority
>0.1	Severe	1
0.05-0.1	High	2
0.01-0.05	Medium	3
0.001-0.01	Low	4
<0.001	Negligible	5

Further analysis has shown that, in tools category, the risk of availability of tools is most important. Also it is dependent on the facility and machine layout. So the improvement strategy should first analyze these entities and then proceed for further improvements based on the final scores. Table 16 can be used for prioritization purposes.

4.5 Conclusion from Assessment

After performing the assessment and evaluating the risks, it is observed that the critical process is prone to the risk of tools being not available followed by tool efficiency and performance. Since the material for the process comes from the preceding process which has higher capability and efficiency, the risk associated with materials for the concerned process is minimal.

Similar assessments were conducted for other processes over a period of time and the following improvement strategy was suggested.

4.5.1 Workplace Organization and Visual Control

Arrangement of the workplace is an important early step to an elevated operational level at the company. 5S is the most visually evident change an organization can make in the eyes of the workforce. A clean, safe environment improves morale on the part of workers. A well-organized, visual environment improves efficiency on behalf of the company.

4.5.2 Standardization:

The time required to perform each task will need to be observed and documented, and then the distribution of tasks among workers will need to be evaluated. Product drying and curing times must be established. This will result in a decrease in product variation and worker confusion and stress levels.

4.5.3 Setup:

Setup time is currently another root cause for the low on-time delivery and high waiting time that is costing the company much of its flexibility. It is accepted as dogma that the total number of setups must be kept minimal. It is therefore necessary to change the culture in this regard and to begin to take advantage of quick-setup concepts. Employees, technicians, or engineers can be educated on methods used to reduce the time for setup procedures. It is not uncommon for setups measured in hours to be reduced to minutes. What this means to the company in addition to more available production time per setup is an opportunity to eliminate changeover as a factor in scheduling.

4.5.4 Pull System Design:

The accuracy of the schedule at the company was the most commonly cited issue. Given the low accuracy of the forecast, the high number of schedule deviations is not unexpected. Determining and exploiting the differing scheduling requirements for company's product types will improve the scheduling process. A move toward pull flow will further allow the impact of forecast changes on production to be minimized.

Pull flow is one of the basic tenants of lean manufacture, and once the proper groundwork is in place it will allow significant improvements in terms of WIP (Work in Process) reduction and throughput time. Formulae exist and are readily obtainable for the calculation of appropriate levels of safety stock, buffer materials, critical WIP, the number of kanban cards needed in a system and the placement of those cards such that work does not stop.

The ability to efficiently manage large quantities of low-volume production runs is a difficult one to attain; however, reaching this level will truly set the company apart from its competitors. It is therefore believed that this should be a future focus for the organization.

Chapter 5

Conclusion

5.1 Introduction

This chapter throws some light on what is achieved by the research work carried out in this thesis. The major section of this chapter summarizes the research done, discusses the study limitations and recommends future research.

5.2 Summary of Research

The main purpose of this research is to develop a “simple” risk assessment and evaluation model for a manufacturer. The foundation of the research is based on the current challenges faced by manufacturers and their corresponding impacts on them. It is found that the risks associated with the resources such as materials, tools etc. are significant and there is not an easy way to identify them in each scenario. Also the models such as MRP and ERP are used at a higher level. The risk management models developed by researchers formed the carcass of the methodology. The tools and the assessments used to execute the methodology were developed on the base of the industry experiences.

The model starts with the classification of different types of risks and identifying these risks for their evaluation. The second step is the identification of the critical process by using PERT/CPM and VSM concepts followed by the risk assessment of the selected process. The risks are then prioritized based on the exposure score calculated using AHP, and OR tool. The same assessment is then used for improving the process and sustaining the changes implemented.

5.3 Comparison of Models

From the literature review we have identified few models that can be used for risk management and analysis. Few of the enlisted models are deterministic, stochastic, economic and simulation. These models find a wide range of applications in the areas of resource optimization and supply chain management. But for the present study, these models lack a bit of feasibility while executing. In order to highlight their shortcomings in reference to the present study, the following comparison was done to show the superiority of the new model over these models for the problem at hand.

A. Deterministic Models:

As described earlier deterministic models comprise of mathematical programming models (e.g. linear, nonlinear, integer, dynamic programming). In order to demonstrate the shortcomings of these models in comparison to the developed methodology, we will use one of the techniques of deterministic models and compare its advantages and disadvantages with the present model.

Example: Linear Programming (LP)

LP is a technique for optimization of an objective function, subjected to constraints. It illustrates a way by which to achieve the best outcome using the available resources and constraints.

Application:

Many practical problems in operations research can be expressed as linear programming problems. Linear programming is heavily used in business management, either to maximize the income or minimize the costs of a production scheme. Some examples are inventory management, portfolio and finance management, resource allocation for human, machine resources and planning advertisement campaigns, etc. [20]

Present Model advantages in comparison to LP:

1. The outputs from Linear Programing depend completely on the input variables that account for the performance of the process. LP gives optimum values for these variables based on the constraints that can only be expressed numerically. For example, to maximize the profit for a variable product mix on a set of machines, the optimum job load will be dependent on the parameters and constraints such as the machine run time for each job, cost to make that product, machine availability, resource availability (raw material etc.) and hence, the objective function will be the total selling price. LP will give the optimum values for each of the above parameters except for the constraints. The major drawback here is that there are many constraints associated with the manufacturing of a product apart from machine run time and resource availability. Constraints that cannot be expressed numerically cannot be addressed in a LP model and their impact remains invisible even though it is critical. The present model analyses the root causes for all the constraints and addresses it to the end user for further investigation.

2. LP models are more mathematical and most of the times rely on softwares for its application which needs some kind of expertise. The present model addresses grass root level problems that can be solved on the shop floor itself by the concerned personnel with limited expertise.
3. Deterministic models as a whole are mathematical and fail to address the intricacies of a shop floor that directly affects the manufacturing of a product. These models need numerical inputs and the outputs are also always numerical. But the issues such as housekeeping and setup cannot be addressed in these mathematical models.
4. Another drawback of deterministic models when compared to other models is, that they do not consider uncertainty while formulating a problem which makes these models more prone to failure in a dynamic environment. It gives a definite number rather than a range or percentile as observed in stochastic modeling.

B. Stochastic Analytical Models:

Stochastic models are assumed to follow a particular probability distribution where at least one of the variables involves uncertainty. The supply chain applications of these models include inventory and production management, where demand and yield are represented as random variables respectively.

Example: Monte Carlo (MC) method

MC methods are a class of computational algorithms that rely on repeated random sampling to compute their results and are often used when simulating physical and mathematical systems. [20]

Application of MC method:

MC methods find applications in finance and reliability engineering. They are useful for modeling phenomena with significant uncertainty in inputs, such as the calculation of risks in the business processes.

Present Model advantages in comparison to MC:

1. There is not a single MC method, but the term describes a class of approaches with the wide range of applications as an optimization tool. Here, random inputs are generated from a defined domain to perform a deterministic computation on these inputs in order to aggregate the results of these individual computations into final result. This is more dynamic than deterministic model, since the output is variable and depends on the range of inputs. But again the variables that cannot be expressed numerically cannot be addressed in a MC model and their impact remains invisible even though it is critical as in the case of deterministic models. The present model analyses the root causes for all the constraints and addresses it to the end user for further investigation.
2. Stochastic models as deterministic models are mathematical and fail to address the intricacies of a shop floor that directly affects the manufacturing of a product.

They need numerical inputs for their models and the outputs are also always numerical though more elaborated as compared to deterministic models. But again, issues such as housekeeping and setup cannot be addressed in these mathematical models.

3. Also most of the times, these models rely on softwares for its application which need some kind of expertise, that is not required for the present model because all the parameters are directly related to activities done on the shop floor.

C. Simulation Models:

Simulation is the imitation of some real thing, state of affairs, or process which generally represent certain key characteristics of a selected system. It is used in many contexts in order to gain insight into the functioning of these systems

In Figure 24 below, the simulation model developed using ARENA demonstrates the functional aspect of the model. The case study is simulated to identify the kind of outputs that can be obtained from it which can be used for the process improvement. The detailed analysis is shown in Figure 25..

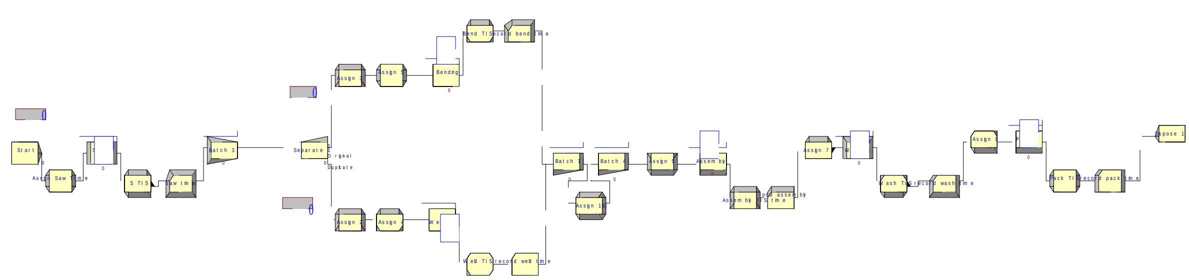


Figure 24 - Arena Simulation Model

The detailed analysis:-

Usage

Utilization

	Value
bend	0.8277
pack	0.01095695
saw	0.6264
wash	0.00442351
weld	0.9998

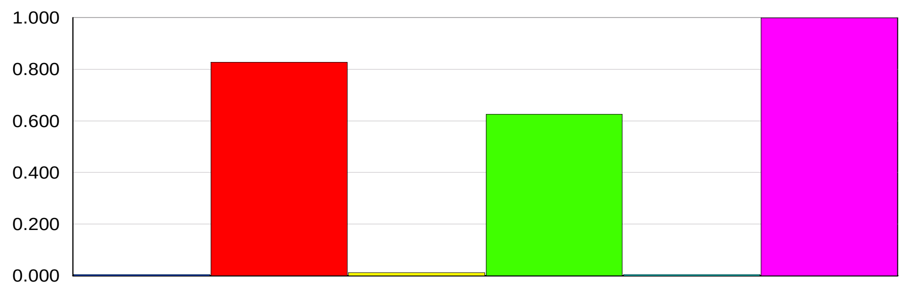


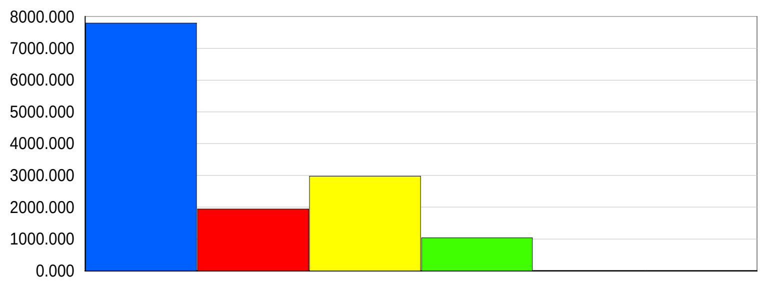
Figure 25 - Percentage Utilization Output from Arena

Simulation starts with the process mapping of manufacturing process where the entire manufacturing scenario is setup in the same way as the process is executed. The simulation is then run for the set period of time to get the results. The results from the simulation model are discussed above. For better understanding, the same process is simulated which is used to validate the methodology.

Figure 26 below shows the percentage utilization of each activity in the manufacturing process. It can be observed that for the selected product, the process of welding is the most critical. The same process is used for the case study to validate the methodology.

Number In

	Value
Bending	1946.00
Packing	2974.00
Sawing	1038.00
Washing	10.0000
Welding	10.0000



Number Out

	Value
Bending	1000.00
Packing	2028.00
Sawing	1010.00
Washing	10.0000
Welding	10.0000

Figure 26 - Average WIP Output from Arena

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Bending.Queue	0.1993	0.012051843	0.00	0.6416
Packing.Queue	0.00	(Insufficient)	0.00	0.00
Sawing.Queue	0.6068	(Correlated)	0.00	1.3410
Washing.Queue	0.00	(Insufficient)	0.00	0.00
Welding.Queue	36.8042	(Correlated)	0.00	73.1754
Number Waiting	**Average**	**Half Width**	**Minimum Value**	**Maximum Value**
Bending.Queue	2.4985	0.138082457	0.00	10.0000
Packing.Queue	0.00	0.000000000	0.00	0.00
Sawing.Queue	15.2846	0.199278209	0.00	49.0000
Washing.Queue	0.00	0.000000000	0.00	0.00
Welding.Queue	459.37	(Correlated)	0.00	917.00

Figure 27 - Average Queue Output from Arena

In Figures 27, it can be observed that simulation models are capable of giving real time details about the process. We can calculate or estimate the average waiting time, queue time, number of parts waiting in a queue etc. to identify the most critical process. Simulation models help us to give optimum values for resources and we can also analyze the effect of disruptions on the overall process but provided we know the probability of its occurrence and its effect in terms of time. Simulation models are more dynamic as compared to deterministic and stochastic models since we can change a single entity or all the entities in a process and observe its impact on the overall output. Accordingly, we can modify the process achieved on the base of the observations from the simulation model.

5.4 Limitations of the Model

There were some limitations in the developed model. One of the limitations is that it did not consider all the variables that could possibly affect a process such as personnel, equipment, maintenance and others. Also some of the elements of the assessment can not be related to some of the manufacturing processes, for example, a machine cutting tool is never used for a process of tube bending. Therefore, it requires awareness on the part of the user who is conducting the assessment. Also, the present model cannot quantify the impact of mitigating various risks associated with the materials and tools on the overall lead time or capability of the process, since they are dependent on more than one variable. Future work can consider this criterion in order to make the model more complete.

5.5 Future Work

A successful Risk Mitigation plan requires an understanding of the specific action and also an understanding of the sequence of methodologies to be implemented. For example, one should not cut the lot size before the setups are reduced. Figure 5.1 represents a general schematic of the order in which implementation is to be undertaken. It is possible to modify the order to some extent based on the needs of the manufacturer.

Since, the study does not involve all kinds of risks within an organization; hence it can be addressed as a methodology for a risk free process rather than a risk free organization. Any company at the initial level maintains what is commonly referred to as "low-hanging fruit"—that is, many opportunities that are both readily identifiable and relatively easy to approach. This in turn enhances buy-in and makes the plant culture more adaptive of further change.

As described earlier, the model does not deal with all kinds of risks that impact the process capability. A generic approach can be followed by the practitioners to develop similar models using the RAM template (Figure 28). It gives a general guideline of how to perform a continuous improvement process. It has a step by step methodology which highlights the tools that can be used to execute the relevant improvement process.

Risk Assessment and Management Template							
	Anticipating	**Infrastructure**	**Designing the Flow**	**Checking for Consistency**	**Support**	**Supply**	**Sustain**
Goal	*Plan for Successful Risk Anticipation*	*Infrastructure Design for Risk Mangement and Mitigation*	*Efficient Flow*	*Variation Reduction by Simulation*	*Support Function*	*Supply Chain Design*	*Sustain by Design*
Issues	Supply Chain Commitment	Asset management	Supply Chain Balancing	Data Collection	Emergent Manufacturing and similar techniques	Supplier Evaluation	Define Risk Measures
	Defining and Categorising Risk	Intellectual Capital	System Mapping (SVSM)	Data Analysis	Human and Equipment Resources	Supplier Selection	Monitor Measures
	Identifying Core Competency	FMEA	System Kanban (Monitoring Stations)	Identifying 'CTR'* Measures		Supplier Development	
	Developing Strategic/process objectives	Training for Risk Mitigation		Understanding Supply Chain Capacity and Effeciency			
		Risk-Proofing techniques					

* CTR - Cost to Risk

Figure 28 - Risk Assessment and Management Template

5.6 Building a Risk-Free Enterprise

The fact that most of the enterprises are at an early stage of implementing risk management and reliability structure makes them prone to errors at the early stages which may lead to the decline in enthusiasm. This section focuses on the education necessary for a long-term change in an organization.

The entire workforce will need to be educated on the some basic principles of process improvement strategies. The workforce will also need to be told how impending changes will benefit each of them on a personal level; otherwise, interest will be low. A series of training sessions are recommended for the following reasons:

- Communication is the key to culture. Unless employees understand why change must occur, they will resist it. Employees are less resistive when they feel they are a part of the process of change.
- The phrase “Risk” or “Reliability” is often seen as nebulous or maybe misinterpreted and will require refinement in the minds of those persons who will be involved.
- A Strategy is built using a set of tools. Some of these tools are simple while some are more technical in nature.
- The process of identifying various improvements can be daunting in the sense that it is difficult to decide on an approach or even where to start. Planning is necessary to ensure that projects are manageable and well defined.

The RAM template is suggested as a model by which both training and the risk management itself may be approached. The progressive nature of the approach allows participants to get a strong start and then develop a cumulative tool set, and each session actually allows a jumping-off point for improvement in the corresponding area. Also note that a short-term approach beginning with identification of related aspects may be inferred by assigning weights. Training is typically rolled out in two stages. The first of these is designed to benefit managers, supervisors, and the decision-makers from whom the change must originate. The goal here is two-fold: get the buy-in from the decision-makers and give them the tools with which to make better decisions. The second stage is designed to impart the same information on a less technical level to the manufacturing personnel themselves and to involve them in the process.

A brief description of each phase:

Phase 1: Risk Anticipation and Planning

The planning phase is one of the most important sessions despite the fact that it is preliminary to the acquisition of tools. This phase begins with the supposition that the organization will decide where it currently is and where it wants to go and that it is now time to begin determining just how to get from one point to the other. Focus is on techniques for rapid transmission of information and allocation of responsibilities. Emphasis is also placed on identifying core competencies within and outside the organization and its associated tools like determining capacity requirements, establishing personnel requirements and risk identification.

Phase 2: Developing an Infrastructure

From the outset of any journey, three pieces of information are of paramount importance. Those are, where is the organization now, where does it want to be and how to get there? Content includes evaluating existing system for available resources and making available other essential elements in terms of equipment, personnel or expertise.

Phase 3: Implementation Flow

This phase develops the concepts of identifying tools through assessments and designing a sequential roadmap of implementing improvement techniques. This includes process mapping, identifying critical processes, aligning resources to improve it and identifying tools to sustain the same.

Phase 4: Standardization, Support and Sustain.

Standardization is one of the preliminary steps necessary for any program to succeed. It should be further noted that standardization does not apply only to typical procedures. Every activity should be planned in a similar/standardized way for every process to achieve an order in the implementation process. Also it will be simpler to design the support functions.

Support functions typically account for over 20% of overall labor expenditures in industry. The first step in streamlining support functions is changing the often rigidly held belief among those individuals working in supportive capacity that improvement techniques apply only to the production environment. Upon achieving this culture, support functions must then be identified and grouped into similar families. These activities may then be approached just as production processes with a series of kaizen events.

To sustain the implemented system it is necessary to monitor it periodically or as scheduled. The success of any implementation rests on how long it can sustain itself.

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Appendix -1

Materials Availability				Yes	No
	Supplier				
		Market	Is there a good materials planning for new products		
			Is there a market study done for raw material availability		
			Is there an alternate plan that exists in case the supplier is common to the competitor		
			Is there a planning for Safety Stock		
		Purchase Dept.	Are Parts history records available		
			Are Engineering drawings/changes kept up to date by the supplier		
			Is there a process in place to ensure accurate stock balance of all inventory types (i.e., finished goods, scrap) and that these stock balance figures are accurately updated		
			Are Components requirements planned correctly		
			Is there a efficient lot size policy		
			Is the order preparation process error proofed		
			Is there a good communication with suppliers regarding orders and delivery requirements		
			Is purchase requisitions issuance on time always		
			Is the needed raw material being determined accurately always		
			Is there a good communication with the suppliers		
			Is there a process to safeguard easily damaged material and high theft material.		
			Is there a accurate inventory record for all materials		

	Are inventory records updated periodically		
	Is there inventory classifications		
	Is there a efficient order policy exists		
	Is there a process that ensures the structure of the Bill of Material (BOM) records are maintained and are accurate.		
	Are records maintained and is the information supplied to all appropriate persons, for evaluations of important materials		
	Is there a process to ensure physical inventory counts and when performed, are done accurately and reported in inventory records.		
	Are the inventory counts performed with an adequate frequency for every part, depending on volume value, waste percentage, etc.		
	Is there a procedure to predict accurate sales forecast		
	Does the MRP receives the expected customer requirements prior to the actual MRP run to calculate daily production operating plans.		
	Is there a good materials planning for new products		
Design Dept.	Are Specifications files available		
	Are Standards files available		
Transportation	Is the Logistics Provider selected and assessed based on logistics, flexibility and quality parameters.		
	Is the transportation planning considered from beginning of the products life cycle and is the Logistics Provider involved during the product development process		
	Is there a process to plan transportation capacity together with the Logistics Provider in line with its own processes and capacities.		

		Has the organization established and documented contingency plans in the event of failure of transport, including quantified alternative methods of transport.		
		Is there a process that tracks and traces in-bound material from time of supplier shipment through to receipt of material.		
		Is there a process that ensures shipping labels are accurate and comply with the labeling standards.		
Internal Planning and Logistics				
	Facility Layout	Is there a control over transferring materials		
		Is there an efficient internal transportations of material		
		Is the process layout efficient in respect to following exist:		
		5S		
		standard work flow		
		mistake proofing		
		cells		
		visual control		
		Is there an efficient tracking system for the location of the materials at all times		
		Is the storage environment appropriately controlled for material on hand, ensuring that all parts have sufficient protection.		
		Is the factory layout efficient and safe		
		Are right material handling equipments used for the right products		
		Is there a sound storage function with good materials location system		

	Do doorways, passageways, and ramps allow ease of movement of the product handled		
	Do product storage methods exist to prevent product crushing and products falls		
	Is compatibility investigated of material to be stored close together		
	Are products properly protected from moisture, severe temperature, leakage, and staining		
	Are all variables that affect the receiving activities considered to balance the utilization of the docks and space (i.e., scheduling, fixed time slots).		
	Is the storage environment appropriately controlled for material on hand, ensuring that all parts have sufficient protection.		
	Is there a process for special loading and material movement		
Stores Department	Are Parts history records available		
	Are Specifications files available		
	Are Standards files available		
	Is there a process in place to ensure accurate stock balance of all inventory types (i.e., finished goods, scrap) and that these stock balance figures are accurately updated		
	Is there a process for Stocks control		
	Is there a standard followed for Packages and containers		
	Is there a control over transferring materials		
	Are records maintained and is the information supplied to all appropriate persons, for evaluations of important materials		
	Is there a process to ensure physical inventory counts and when performed, are done accurately and reported in inventory records.		

Are the inventory counts performed with an adequate frequency for every part, depending on volume value, waste percentage, etc.		
Is there a periodic evaluation for part storage, part movement and accurate inventory records using error reduction tools (i.e., visual controls, bar coding, elimination of manual entry),		
Are the materials properly packed and handled		
Is there an efficient tracking system for the location of the materials at all times		
Is the storage environment appropriately controlled for material on hand, ensuring that all parts have sufficient protection.		
Is there a process to safeguard easily damaged material and high theft material.		
Is there a sound storage function with good materials location system		
Are engineering problems considered in storing		
Compression strength for hard to store products		
Cushioning for fragile products		
shelf life for sensitive products		
Impact and vibration of filling packages		
packaging operations configurations		
Do product storage methods exist to prevent product crushing and fall		
Is compatibility investigated of material to be stored close together		
Are products properly protected from moisture, severe temperature, leakage, and staining		
Are incoming materials appropriately unpalletized or containerized		
Is there a proper unloading mechanization		
Does the unloading occur in a logical and orderly fashion		

		Are all variables that affect the receiving activities considered to balance the utilization of the docks and space (i.e., scheduling, fixed time slots).		
		Is there a process for special loading and material movement		
	Planning Dept.	Are Engineering drawings/changes kept up to date		
		Is there a process in place to ensure accurate stock balance of all inventory types (i.e., finished goods, scrap) and that these stock balance figures are accurately updated		
		Is there a accurate analysis process for quotation/ or proposals		
		Is there a system for new supply sources development		
		Is there an alternative for materials and sources		
		Is there a process that ensures the structure of the Bill of Material (BOM) records are maintained and are accurate.		
		Are records maintained and is the information supplied to all appropriate persons, for evaluations of important materials		
		Is there an efficient planned load and load leveling procedure for work orders		
		Is there a a standardized procedure exist to expedite orders		
		Is there a planning function to allocate resources to ensure adequate capacity (personnel, equipment, maintenance and layout/space).		
Quality				
	Supplier Process	Are Suppliers evaluated according to the quality control standards(purchasing are familiarized with these standards)		
		Is there a process of supplier plant visits and inspections		
		Is the system ISO/QS 9000 complied		

		Are necessary test specifications and operating instructions submitted to the quality control		
		Is the design Validated using the following:		
		Failure prevention analysis		
		Field tests		
		Failure mode analysis		
		Calibration equipment		
		Product testing-design		
		Product testing-production processes		
		Are products properly packed and handled		
QA Dept.	Audit	Are Materials checked upon receipt		
		Is the system ISO/QS 9000 complied		
		Are necessary test specifications and operating instructions given to the quality control		
		Are there definite and standard procedures for the evaluation of a product		
		Are quality problems well managed via the following:		
		Scrap/rework reduction		
		Feedback of Q/R and failure information		
		Warranty reduction		
		Are unacceptable goods identified by quality control upon receipt		
		Are suppliers being evaluated according to the delivery control standards		
		Does Inspection & testing exist as follows		
		Inspection direct 100%		
		Inspect direct less 100%		

		Quality audits		
		Material for inspection & test		
		Receiving inspection & storage		
		Lab accept testing receiving inspection		
		Lab accept testing production area		
		Outside lab services		
		Field testing		
		Are unacceptable goods identified by quality control upon receipt		
	Other	Is there a good quality management system to coordinate planning and production.		
		Is the management committed to quality		
		Are complete drawings and bills of materials being reproduced and forwarded to quality department		
		Are operators trained on quality and reliability		
		Is there a good information system with the quality department		
Specifications				
	Supplier	Are Specifications files available with the supplier		
		Are Standards files available with the supplier		
		Are the suppliers capable of meeting all specification requirements		
		Is the system ISO/QS 9000 complied		
		Does Manufacturing Engineering studies the design, manufacturing phases, necessary drawings, and bills of materials before production		
		Are clear prints from customer and finishing route sheets attached with every work order		

	Are necessary test specifications and operating instructions followed while production		
Design Dept.	Are vendor specifications established		
	Are engineering drawings/changes kept up to date		
	Are Production specifications changes updated regularly		
	Is there a process to periodically evaluate, error reduction tools (i.e., visual controls, bar coding, elimination of manual entry)		
	Is there a good communication with suppliers regarding orders and delivery requirements		
	Is the system ISO/QS 9000 complied		
	Are complete drawings and bills of materials being reproduced and forwarded to production and quality		

Tools Availability				Yes	No
	Supplier				
		Market	Is there a good part planning for new tools		
			Is there a market study done for special tool availability		
			Is there an alternate plan that exists in case the supplier is common to the competitor		
			Is there a planning for Safety Stock		
		Purchase Dept.	Are tools history records available		
			Are tool specifications files available		
			Are Standards files available		
			Is the order preparation process error proofed		
			Is there a good communication with suppliers regarding orders and delivery requirements		
			Is purchase requisitions issuance on time always		
			Is there a good communication with the suppliers		
			Is there a efficient order policy exists		
		Production Dept.	Are tool requirements planned correctly		
			Is there a efficient lot size policy		
			Are the needed tools being determined accurately always		
			Is there a accurate inventory record for all toolss		
			Are inventory records updated periodically		

	Is there inventory classifications		
	Are records maintained and is the information supplied to all appropriate persons, for evaluations of important tools		
	Is there a process to ensure physical inventory counts and when performed, are done accurately and reported in inventory records.		
	Are the inventory counts performed with an adequate frequency for every part, depending on volume value, waste percentage, etc.		
	Is there a good tools planning for new products		
Transportation	Is the Logistics Provider selected and assessed based on logistics, flexibility and quality parameters.		
	Is the transportation planning considered from beginning of the products life cycle and is the Logistics Provider involved during the product development process		
	Is there a process to plan transportation capacity together with the Logistics Provider in line with its own processes and capacities.		
	Has the organization established and documented contingency plans in the event of failure of transport, including quantified alternative methods of transport.		
	Is there a process that tracks and traces in-bound material from time of supplier shipment through to receipt of material.		
	Is there a process that ensures shipping labels are accurate and comply with the labeling standards.		

Internal Planning and Logistics				
	Workplace Layout	Is there an efficient internal transportations of tool		
		Is the process layout efficient in respect to following exist:		
		5S		
		standard work flow		
		mistake proofing		
		cells		
		visual control		
		Is there an efficient tracking system for the location of the tools at all times		
		Is the storage environment appropriately controlled for tool on hand, ensuring that all parts have sufficient protection.		
		Is there a process to safeguard easily damaged tool and high theft tool.		
		Is the layout around the machine efficient and safe		
		Are right tool handling equipments used for the right products		
		Is there a sound storage function with good tools location system		
		Do product storage methods exist to prevent product crushing and falls		
	Prodn. Planning and Control	Are tool history records available		
		Are tool specifications files available		
		Are Standards files available		
		Is there a accurate analysis process for quotation		

	Is there a system for new supply sources development		
	Are records maintained and is the information supplied to all appropriate persons, for evaluations of important tools		
	Is there a planning function to allocate resources to ensure adequate capacity		
	Is there a process for special tools movement for heavy tools		
Machine	Is there a process in place to ensure accurate stock balance of all inventory types and that these stock balance figures are accurately updated		
	Is there a process for Stocks control		
	Is there a control over transferring tools		
	Is there an alternative for tools and sources		
	Are records maintained and is the information supplied to all appropriate persons, for evaluations of important tools		
	Is there a process to ensure physical inventory counts and when performed, are done accurately and reported in inventory records.		
	Are the inventory counts performed with an adequate frequency for every part, depending on volume value, waste percentage, etc.		
	Is there a periodic evaluation for part storage, part movement and accurate inventory records using error reduction tools (i.e., visual controls, bar coding, elimination of manual entry),		
	Are the tools properly handled		
	Are right tool handling equipments used for the right products		
	Is there an efficient plan for tool handling maneuvering		
	Is compatibility investigated of tools to be stored close together		
	Are tools properly protected from moisture, severe temperature and		

	staining		
	Are incoming tools appropriately sorted and stored always		
	Is there a proper tool handling mechanization		
	Is the storage environment appropriately controlled for tool on hand, ensuring that all parts have sufficient protection.		

Tools				
Efficiency			Yes	No
	Workpiece	Is the work piece material appropriate for the tool used		
	Tool	Is the right tool size used for the job		
		Is the right tool used for the said machining process		
		Is the tool material appropriate for the work piece		
		Is the tool wear monitored		
		Are the tool edges checked periodically		
		Does the machine tool produce same dimensions with one setting repeatedly		
		Is the MTBF (Mean time between failures) for the tool high		
		Is the MTTR (Mean time to repair) less		
		Does the machine tool have sufficient strength to maintain a sharp cutting edge		
		Does the machine tool have sufficient resistance to stand wear of cutting edges		
		Does the machine tool have sufficient hardness to withstand wear from chips		
	Machining Parameters	Are the cutting parameters calculated before machining		

		Is the machine operated using the calculated parameters (i.e., speed, feed, depth of cut)		
		Is a new process monitored to check the amount of heat generated due to high speeds or lack of cutting fluids		
		Is the proper type of cooling (liquid or air) incorporated for specific materials of work pieces		
	Machine	Is the machine operated using the calculated parameters (i.e., speed, feed, depth of cut)		
		Are the right tool holding devices (collets, chucks) used for the operation		
		Is the machine vibration free, or are vibration levels under the threshold limits		
		Is the cutting operation vibration and noise free		
			Yes	No
Performance	Operation Output	Is the work piece material appropriate for the tool used		
		Is the right tool size used for the job		
		Is the right tool used for the said machining process		
		Is the tool material appropriate for the work piece		
		Are the machining parameters calculated before machining		
		Is the machine operated using the calculated parameters (i.e., speed, feed, depth of cut)		
		Is the right work holding device used for the work piece in order to avoid interference with the tool in operation		
		Does the tool provide the required surface finish		
		Does the tool always produce the desired shape and size		

	Is the tool capable of producing/machining accurate jobs over the entire period of its life		
	Does the tool produce broken chips (and not continuous or chips with built-up edges)		
	Does the tool have chip breaking edges		
	Does the machine tool produce same dimensions with one setting repeatedly		
	Is the MTBF (Mean time between failures) for the tool high		
	Is the MTTR (Mean time to repair) less		
	Does the tool have the ability to produce accurately in regard to dimensional geometry and surface finish without calling for much expertise of the operator		
	Is the machine tool robust in design		
	Is the tool dynamically stiff (vibration level of the machine below the natural frequency of the operating tool)		
	Is the tool easily identifiable for a specific operation based on its nomenclature/signature		
	Does the tool force has a negative effect on work piece (distortion due to mechanical force or due to heat generation)		
	Does the machine tool have sufficient strength to maintain a sharp cutting edge		
	Does the machine tool have sufficient resistance to stand wear of cutting edges		
	Does the machine tool have sufficient hardness to withstand		
Tool Maintenance	Is the tool wear monitored		
	Are the tool edges checked periodically		

	Are the tools stored in a correct manner (using wax coatings or covers to avoid damage to cutting edges)		
	Is a new process monitored to check the amount of heat generated due to high speeds or lack of cutting fluids		
	Is the proper type of cooling (liquid or air) incorporated for specific materials of work pieces		
Other	Is the right cutting fluid used during the machining operation		
	Is the tool easy in operation and maintenance		
	Is the tool aesthetically good (no protruding parts etc.)		
	Are the right tool holding devices (collets, chucks) used for the operation		
	Is the machine vibration free, or are the vibration levels under threshold limits		
	Is the cutting operation vibration and noise free		
	Is the machine tool easy to handle		
	Is the machine tool safe during operation		
	Is the machine tool easy to store		
	Is the tool cost-efficient		
	Are the operators trained to use the machine tools		
	Are appropriate safety measures employed while using the machine tool		

Appendix – 2

Sample AHP Calculation

	Material	Tools
Material	1.00	2.00
Tools	0.50	1.00
Total	1.50	3.00

	Material	Tools	***Average***
Material	1/1.5 = 0.6666	2/3 = 0.6666	***0.67***
Tools	0.5/1.5 = 0.3333	1/3 = 0.33333	***0.33***

A. For Materials

	Availability	Quality	Specifications
Availability	1.00	2.00	4.00
Quality	0.50	1.00	3.00
Specifications	0.25	0.33	1.00
Total	1.75	3.33	8.00

	Availability	Quality	Specifications	***Average***
Availability	1/1.75 = 05714	2/3.33 = 0.6	4/8 = 0.5	***0.56***
Quality	0.5/1.75 = 0.28	1/3.33 = 0.3	3/8 = 0.375	***0.32***
Specifications	0.25/1.75 = 0.14	0.33/3.33 = 0.1	1/8 = 0.125	***0.12***

B. For Tools

	Availability	Performance	Efficiency
Availability	1.00	5.00	3.00
Performance	0.20	1.00	0.50
Efficieny	0.33	2.00	1.00
Total	1.53	8.00	4.50

	Availability	Performance	Efficiency	***Average***
Availability	1/1.53 = 0.65	5/8 = 0.625	3/4.5 = 0.66	***0.65***
Performance	0.2/1.53 = 0.13	1/8 = 0.125	0.5/4.5 = 0.11	***0.12***
Efficiency	0.33/1.53 = 0.21	2/8 = 0.25	1/4.5 = 0.22	***0.23***

AHP

Preference	Numerical Rating
Extremely Preferred	9
Very Strongly to Extremely	8
Very Strongly Preferred	7
Strongly to very strongly	6
Strongly Preferred	5
Moderately to strongly	4
Moderately Preferred	3
Equally to Moderately	2
Equally Preferred	1

Vita

Ashutosh Hengle was born on 12th June, 1983, in Maharashtra, India. He studied in Pune, India until his B.E. He obtained his Bachelors in Engineering degree in Mechanical Engineering from University of Pune. He graduated in August 2004 with a First Class. He worked for a year with Pam Pac Machines Pvt. Ltd. as Management Trainee. He joined the University of Tennessee, Knoxville to pursue his Master's degree in Industrial Engineering. His thesis work was supervised by Dr. Rapinder Sawhney. He developed an assessment model for his thesis titled "A Methodology to Assess and Manage Material and Machine Tool Risks for a Manufacturer". During his masters he worked as a Graduate Research Assistant under Dr. Sawhney and worked on many interesting Industrial projects.